Characteristics and quality assurance of gamma images

Uniformity of detector response

- Gamma camera must give a uniform response to a uniform field (1-2 % non uniformity is acceptable)
- Check up test

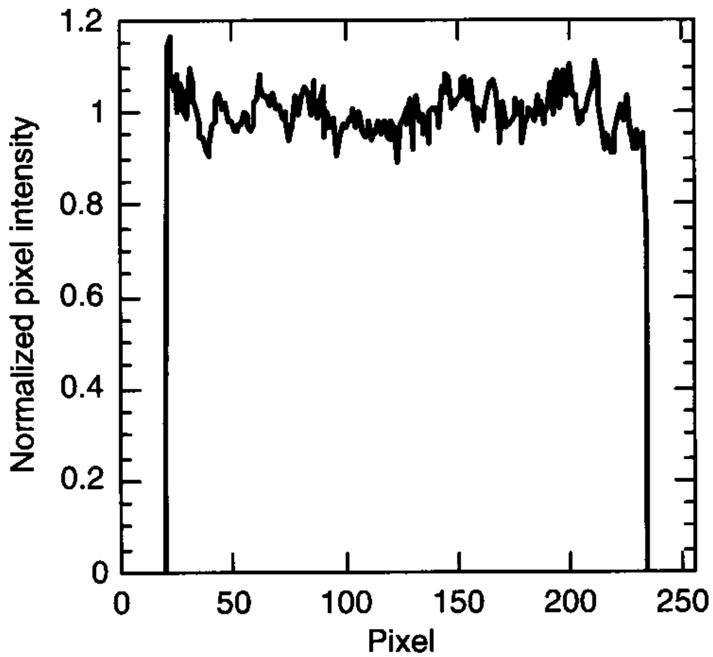
1) Uniformity of conventional gamma camera: flood field or shield phantom Test

   – A flat sealed plate filled with Co-57 (similar gamma emission as Tc but long lived) is imaged

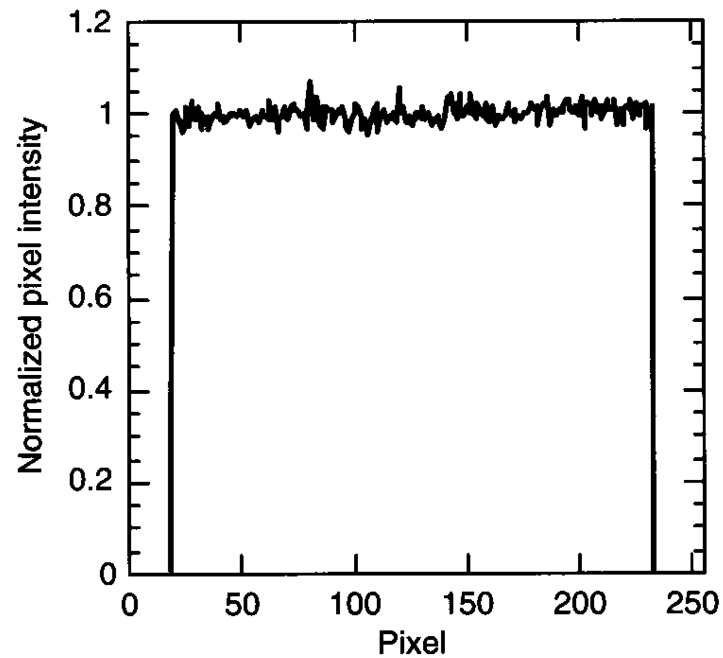
- Causes of gamma camera non uniform response
  - Defective photomultiplier → area of reduced counts

– Cracked crystal → linear defect

– Non uniformity caused by usual slight differences in the performance of photomultiplier: detected by analyzing pixels counts, and compensated automatically

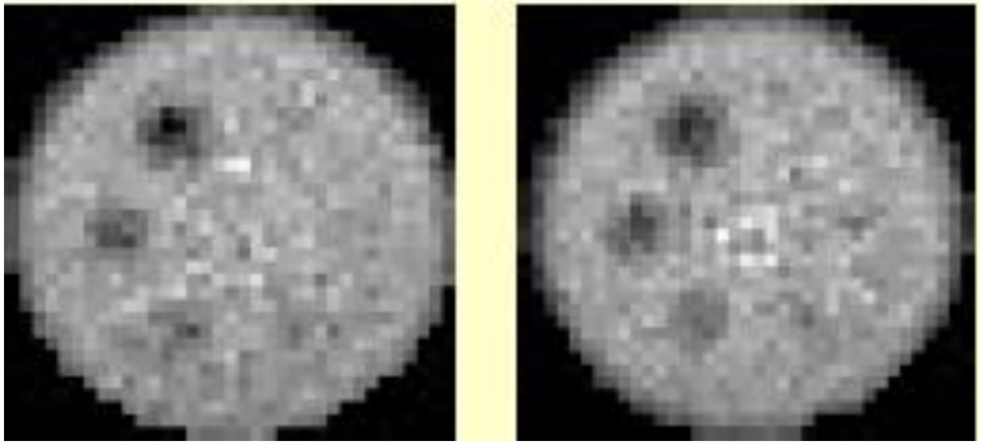


No correction

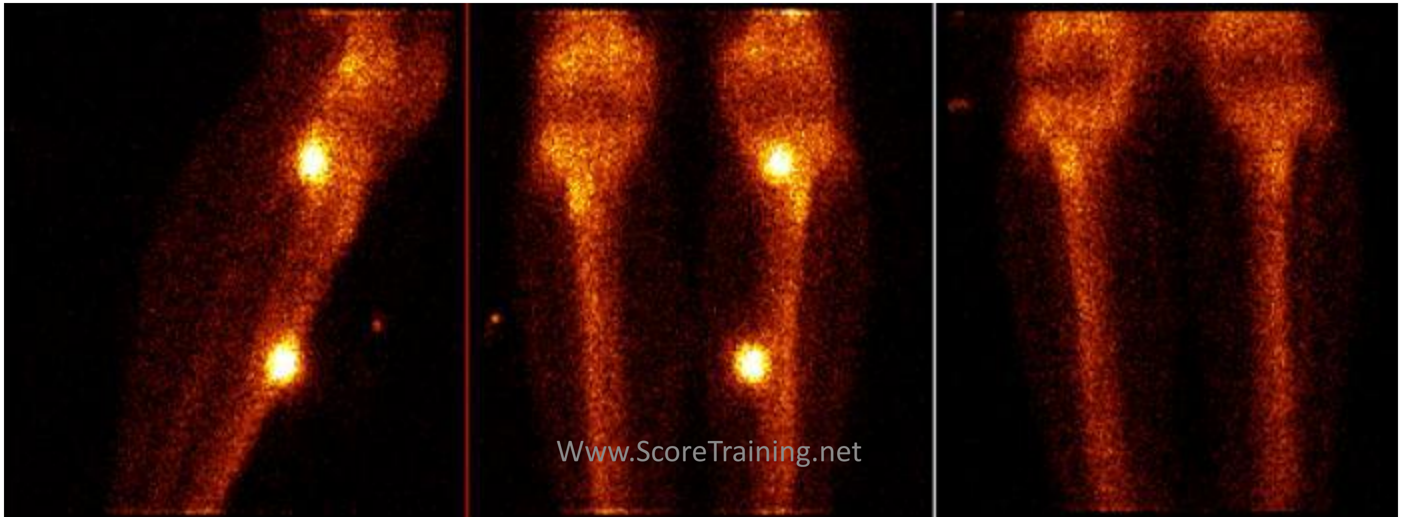


Corrected

– Contamination of the crystal or camera head → high reading obtained whatever the camera orientation

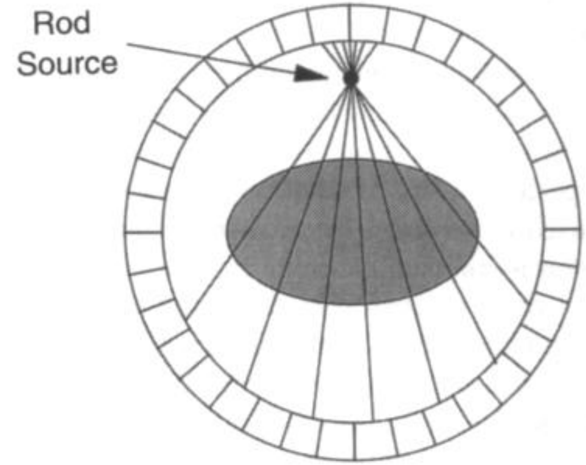


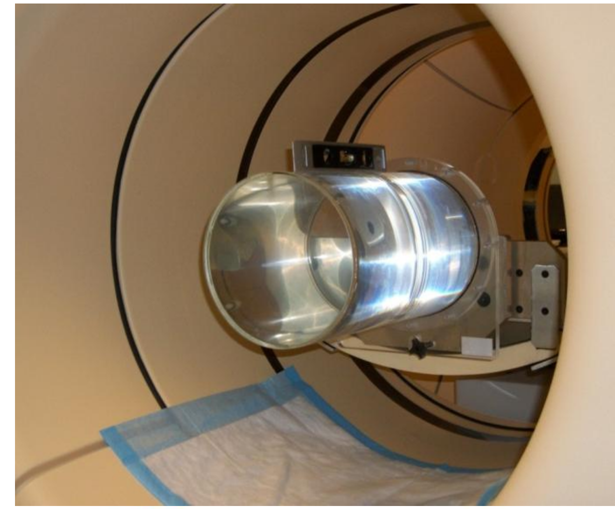
– Collimator contamination → high reading only when collimator is in place

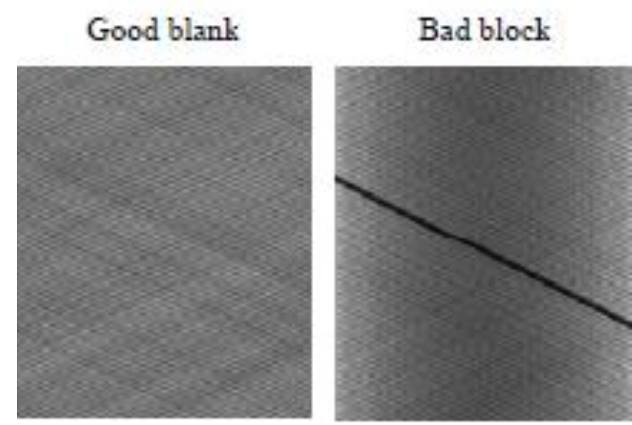


2) **Uniformity of PET scanners:**

- Ge-68 or Cs-137 (long lived sources) are mounted on the gantry → rotating it around the field to expose all the detectors uniformly
- Another method: phantom with centrally located positron source
- Sinogram should be uniform
- Detector block malfunction → diagonal streak covering all the angles with each coincidence detector blocks



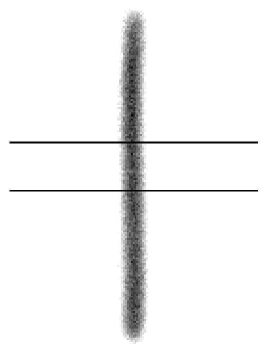


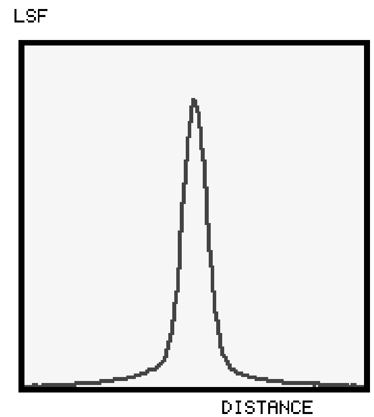


Spatial resolution of gamma camera

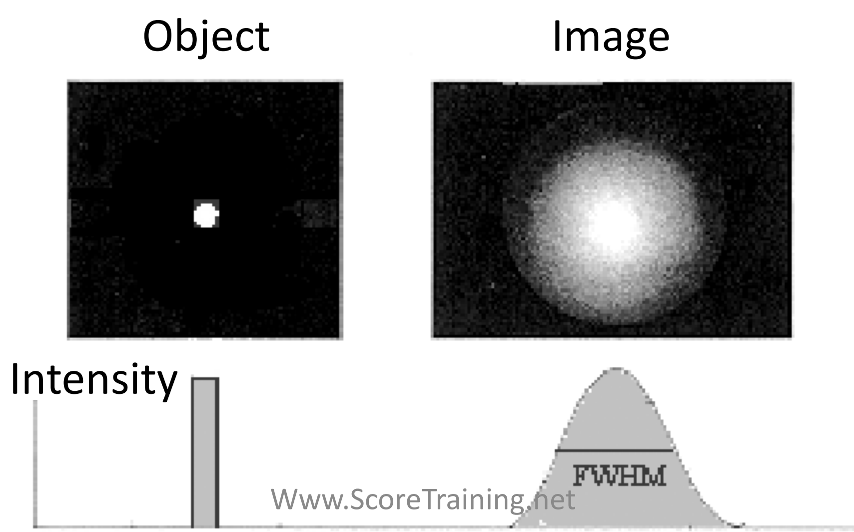
<u>1- line spread function:</u>

- Graph in which counts are plotted along a line of pixels perpendicular to a thin tube of Tc





•FWHM = full width at half maximum: measure the spread of the curve (↑FWHM→↓Resolution)



Types of spatial resolution measured:

A) system resolution at the face of collimator:

- Line source is placed against the collimator face in air
- FWHM is less than 5mm

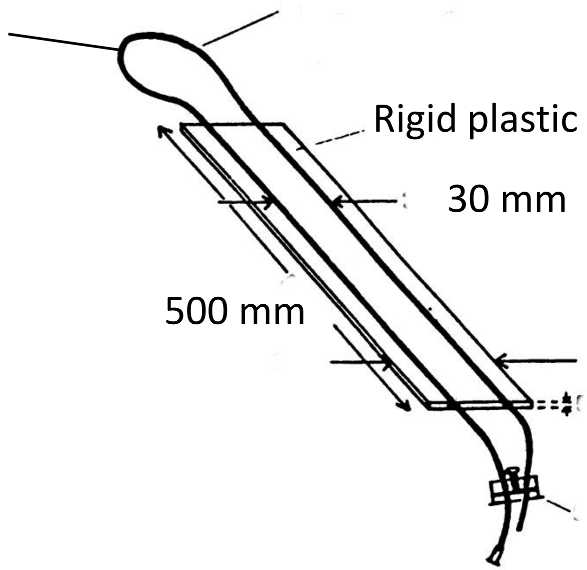
B) intrinsic resolution:

- line source 50 mm from uncollimated camera head (source itself is collimated)
- FWHM = 1-2 mm

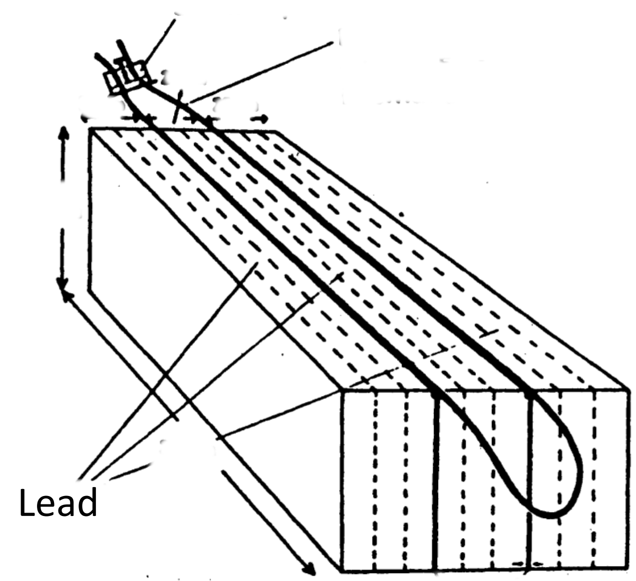
C) system resolution at depth:

- Depth is chosen to match that of the organ imaged (e.g. 10 cm deep in a scattering medium)
- Using a collimator
- FWHM = 10 mm

System resolution



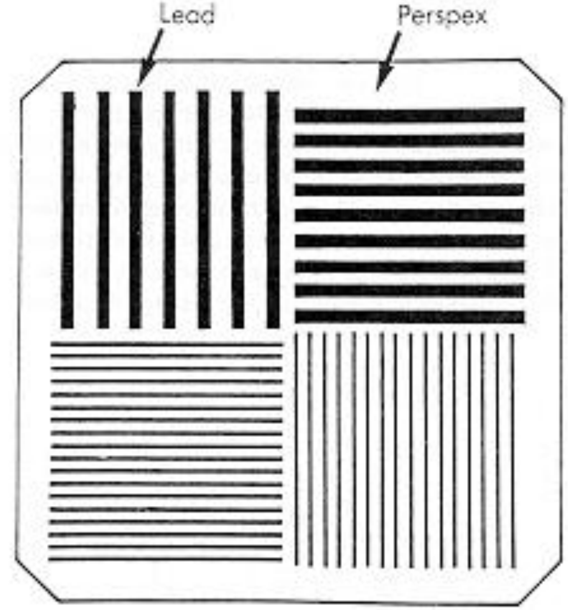
Intrinsic resolution

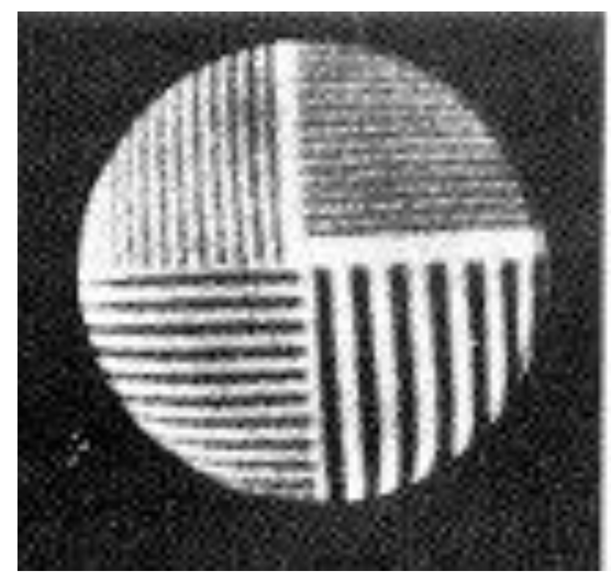


2- bar test pattern:

For system resolution :

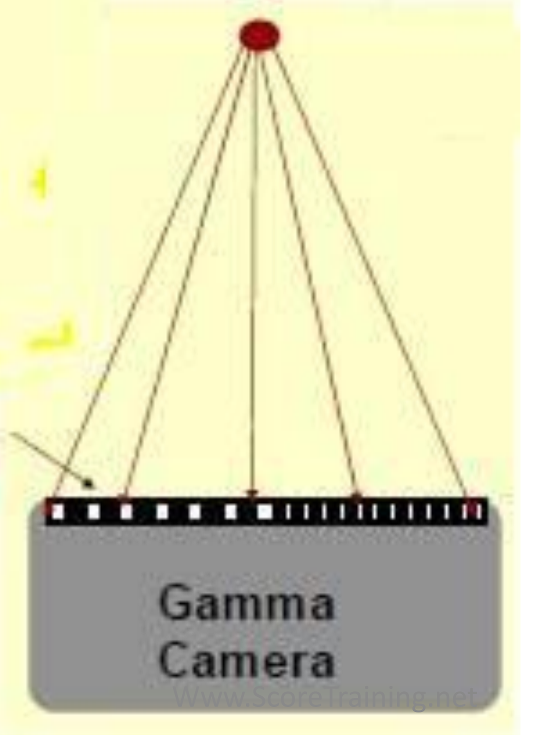
- bar pattern is placed between sheet source and the multihole collimator
- System resolution depends on
  - intrinsic resolution
  - collimator resolution





For intrinsic resolution:

Bar pattern is placed replacing the collimator & a point source is used at a distance to produce uniform photon flux on camera surface



Gamma imaging resolution in practice:

- Not better than 5 mm
- No need for more resolution (evaluate function not anatomy)
- Resolution is not improved by using pixel size less than 3 mm (128 x 128 matrix)

Testing Spatial resolution of PET scanners

Line sources is used (Ge-68 or Na-22) spaced apart at two axial planes:

a) Transverse resolution: sources are parallel to Z axis

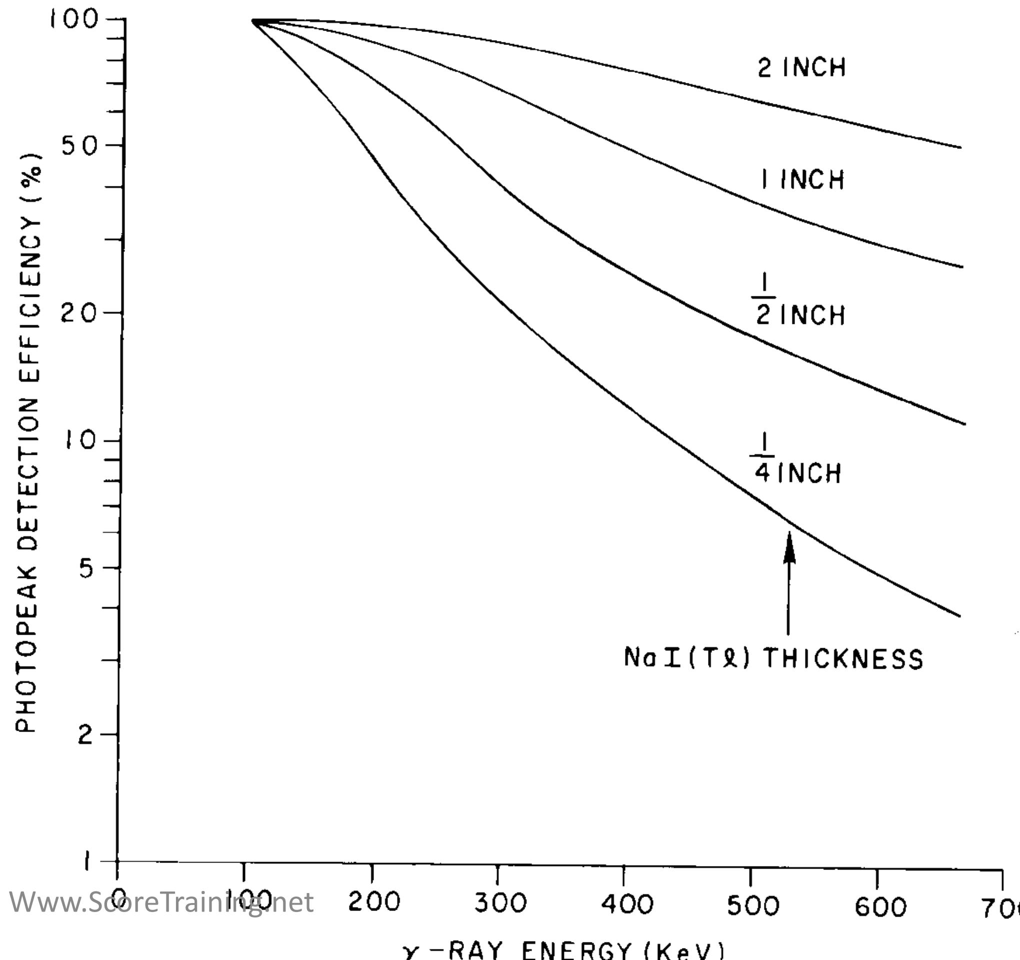
b) Axial resolution: sources in transaxial plane

Gamma camera sensitivity or efficiency

- **Sensitivity**: measured in cps/MBq
- **Efficiency**: measured in percentage (of the activity which is detected)
- Both Depends on

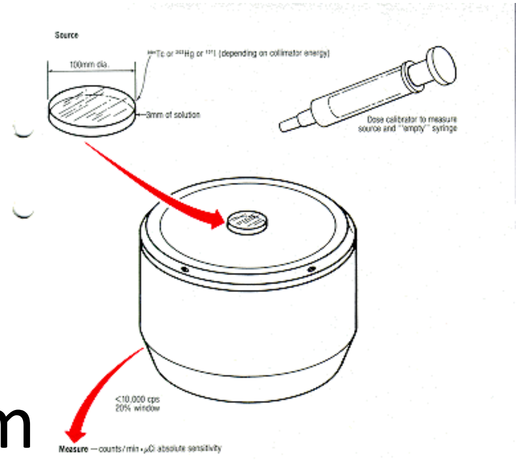
<u>1- detector = intrinsic detection efficiency :</u>

- Percentage of gamma rays absorbed by the crystal after passing through collimator
- About 100% up to 100 kev
- Above this energy → it depends on crystal thickness (↑thickness →↑sensitivity &↓resolution)



2- collimator sensitivity:

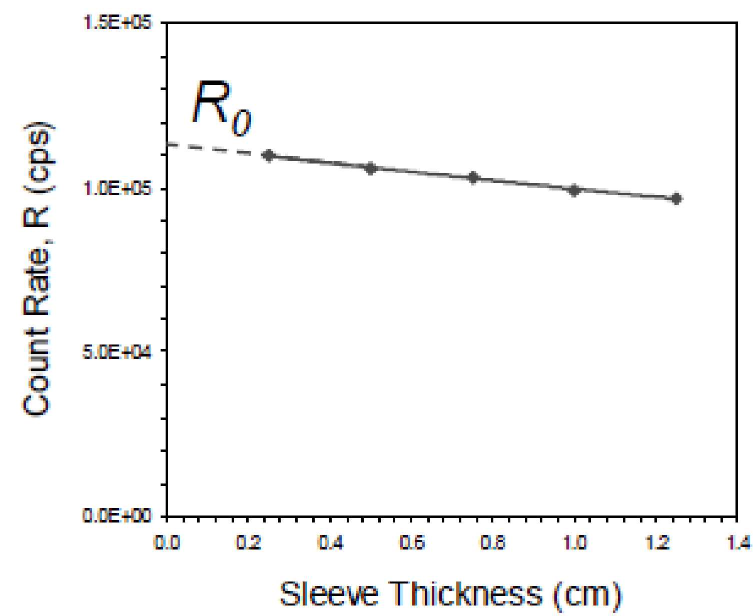
- percentage of gamma rays which pass through the collimator
- The collimator is the main factor determining the overall sensitivity
- Depends on
  - septa thickness (thicker septa are used for higher gamma energies)
  - Holes width (↑width →↑sensitivity &↓resolution)



- Sensitivity is α $FWHM^2$
- Method of measurement: sheet phantom

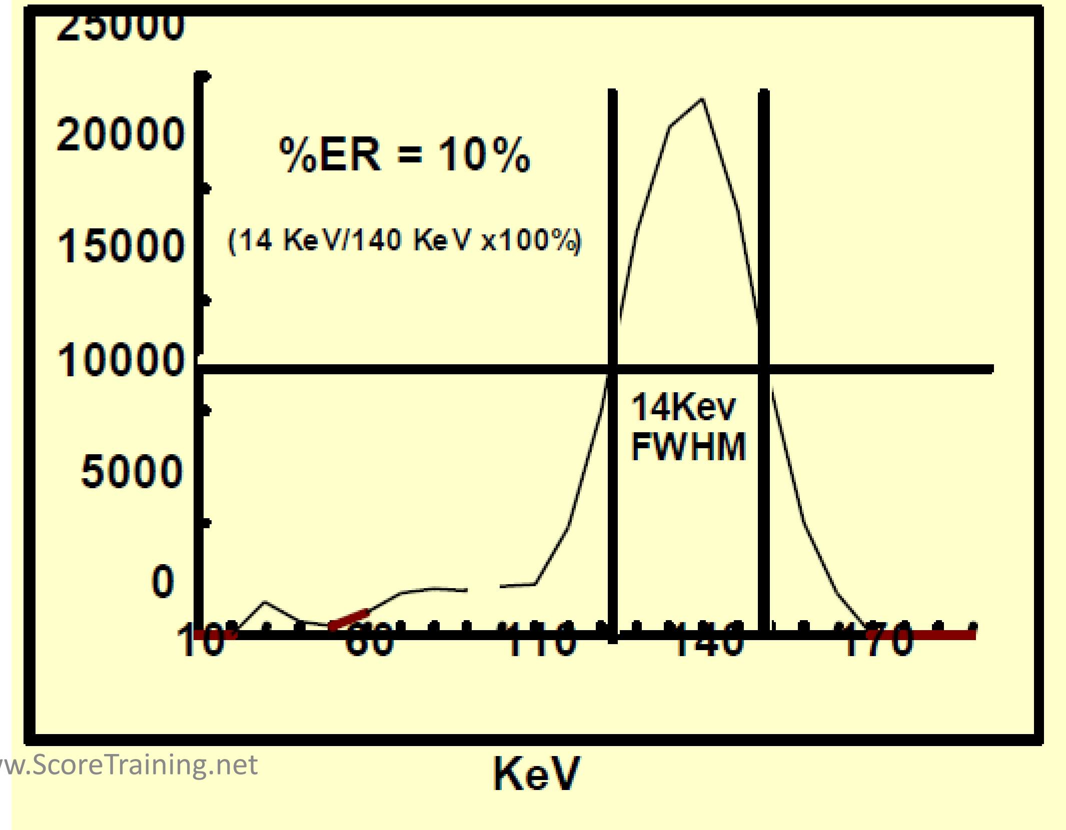
Measuring PET scanners sensitivity

- Test:
  - long tube filled with low activity of positron emitter at the center of FOV & parallel to Z axis
  - Energy window is set at 100 kev above and below 511 kev
  - Data collected with different thickness of metal sleeve around the source tube
  - The total count rate for each sleeve is analyzed , and the result is extrapolated to zero sleeve thickness
- Sensitivity of 2D systems is 5cps/Bq
- 4 times better for 3D systems

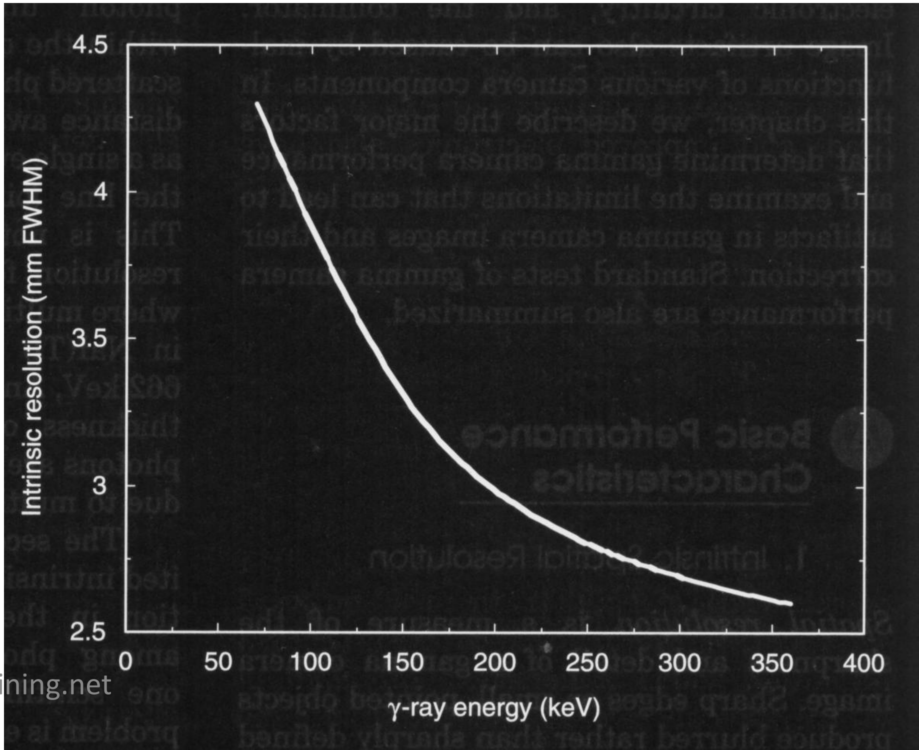


Energy resolution

- Definition: ability to distinguish between separate γ rays of different energies
- = FWHM of photopeak (plotted by PHA) expressed as a percentage of photopeak height
- At 140 kev: E resolution = 10-12% for most camera (when this percentage decrease → E resolution ….)
- The better is the energy resolution , the better is the rejection of scatter , and the better is the spatial resolution



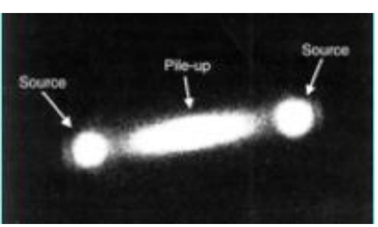
- E resolution depends on:
  - 1) γ energy:
    - when increased → more light photons → increase of photopeak height → increase of E resolution
    - E resolution for Tc-99 is better than Tl-201
  - 2) detector light production:
    - In PET: light yield for BGO is less than NaI →E resolution is less
  - 3)effective Z and thickness of the crystal:
    - increase E resolution



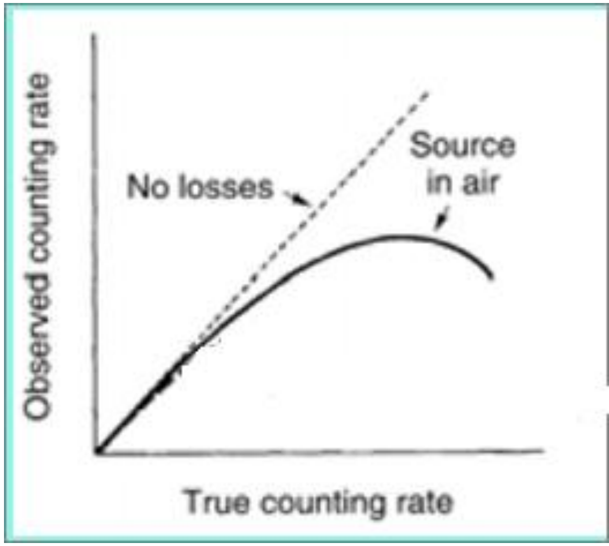
Temporal resolution

- **Scintillation decay time:**
  - fraction of microsecond delay of flash of light produced in the crystal as response to γ photon
  - Scintillation decay time **is** fastest for PET detectors

- **Dead time**:
  - total time for the electronics to register the output of photomultiplier tube for each event in the crystal
  - Includes: light production , pulse production and count registration
  - during this time circuits does not recognize other undependable pulses
  - as counts arrive in irregular interval, a 2nd γ photon may enter the detector during the dead time with the following possibilities:
    - Non-paralizable system: Second pulse is ignored
    - Paralizable system: The two pulses are added, e.g.:
      - Combined photopeak pulses → rejected by PHA
      - Combined two scatter pulses → recorded as event in a false location



- Result: At high count rate:
  - Spatial resolution deteriorates
  - Count rate is underestimated (missed counts) e.g. in 40000 cps → 20% dead time loss & more in higher count rates

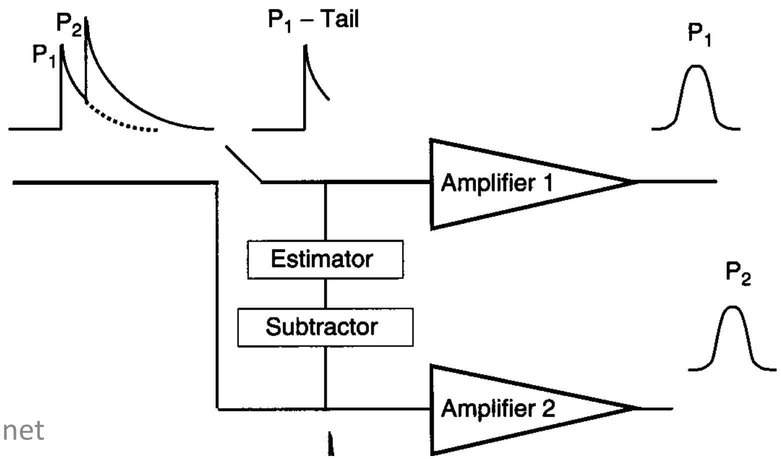


- To compensate for dead time losses:
  1- correction by using measurements of count rates as a function of observed count rate

  2-using buffers to store the overlapping events → reducing the dead time losses

  3-high speed electronics

  4-pulse pile up rejection circuits

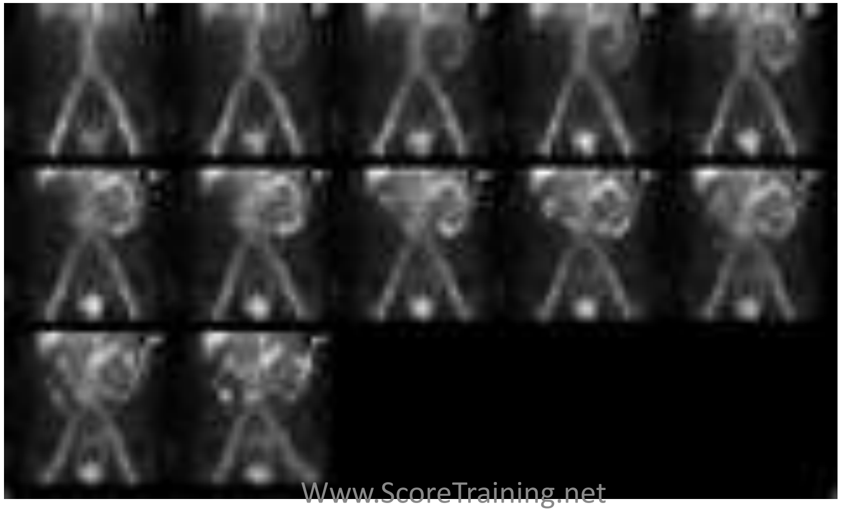


Gamma imaging and noise

- The greater is the number counts/pixel → the smaller is the standard deviation → the better is the SNR

e.g. if 100 count/pixel → pixel to pixel noise = 10%

- Noise in gamma imaging is generally high due to limited amount of radioactivity reaching the camera



- To decrease noise:

1- we may increase the activity administrated , but this is limited by:
  - Acceptable patient dose
  - 20% only of the tracer is concentrated in the organ of interest
  - Small fraction of γ rays pass through the collimator (to increase this sensitivity spatial resolution is scarified)

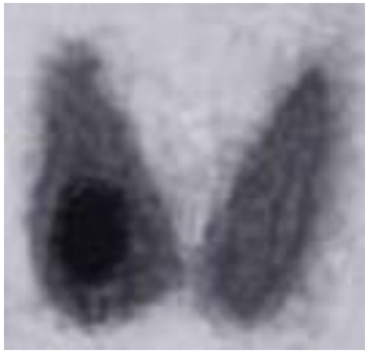
2- we can also increase the scanning time , but this is limited by:
  - Patient movement → decrease of contrast
  - Biological removal of activity from the organ of interest
  - Camera work-load
  - Dynamic studies need multiple images in rapid succession

Noise in PET

- Noise equivalent count rates=
  true coincidences / total coincidences
- Noise equivalent count rates is α SNR
- measured using standard phantom centered in the FOV

Gamma imaging contrast

- Depends on
  - difference in radionuclide concentration between pathological and normal tissues
    - α number of counts acquired per unit area of ROI
  - Noise: to detect hot (or cold) spot which is 10% more (or less) than background → noise level must be less than 3%



Nuclear medicine and patient dose

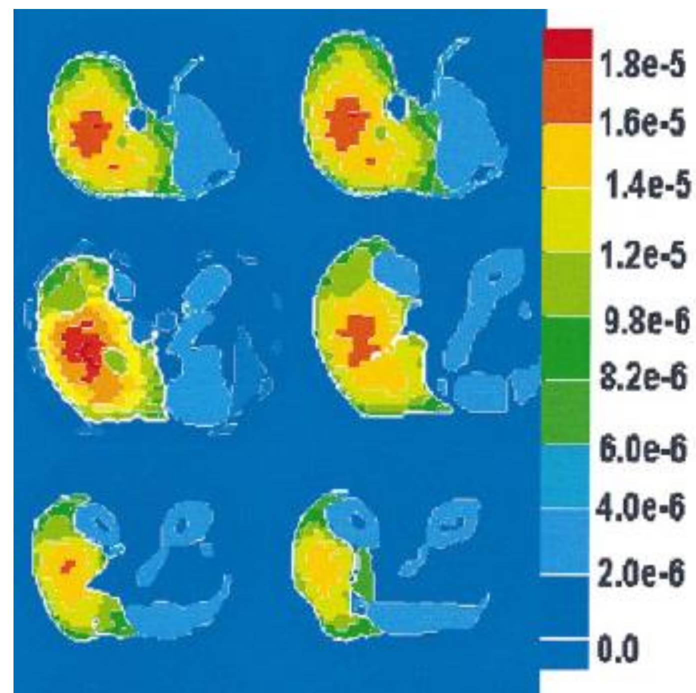
Factors affecting absorbed dose delivered to an organ

- Activity administrated
- Fraction taken up by the organ
- Effective half life of the activity in the organ
- Energy of β and γ radiation emitted
- Fraction of the energy escapes from the organ
  – Almost all β energy is deposited inside the organ and very little escapes
  – Some of γ energy is deposited in the organ and some leaves it

Calculation of internal absorbed dose

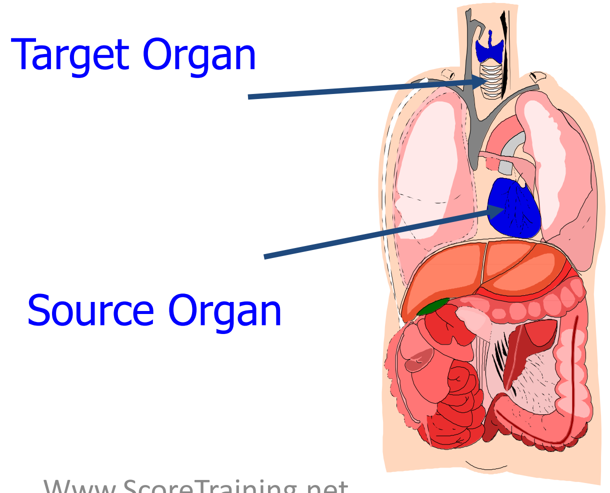
1- monte carlo method

- Mathematical simulation of the patient anatomy based on CT image
- Mathematical methods that consider the fate of individual photons whose behavior determined in terms of probabilities



2- Medical internal radiation dose (MIRD)

- Method of American society of nuclear medicine
- Assumes that there are source organ which accumulates the activity , and target organs which are irradiated by the source organ



Cardiac scan

Dose after colloid scan

Target Organ	w_T	Absorbed Dose (mGy)	Effective dose (mSv)
Gonads (F)	0.2	0.081	0.016
Red Marrow	0.12	0.41	0.049
Colon	0.12	0.07	0.008
Lung	0.12	0.2	0.024
Stomach	0.12	0.23	0.028
Bladder	0.05	0.04	0.002
Breast	0.05	0.1	0.005
Liver	0.05	2.74	0.137
Esophagus	0.05	0.1	0.005
Thyroid	0.05	0.03	0.0015
Bone Surfaces	0.01	0.24	0.0024
Spleen	0.025	2.85	0.071
Remainder	0.05	0.21	0.005

Notes:
- Calculations are approximate (exact uptake is dependant on body size , age , sex , disease…..)
- dose can be measured based on activity uptake measured from gamma images
- After IV tracer injection most of organs receive dose (compare to x-ray)
- Target organs and organs of excretion receive highest dose
- Distribution of the dose is examination specific

Typical activities and doses

exam	agent	Activity (MBq)	Effective dose
bone	Tc MDP	600	5
LUNG VENTILATION	Tc 99m DPTA aerosol	80	0.5
Lung perfusion	Tc 99m HSA	100	1
Kidney	Tc 99m DPTA	300	2
Infection	Ga 67	150	15
Thyroid	I-123	20	4
Heart	Tl-201	80	18

Notes:

- Most nuclear medicine investigations deliver less than 5 mSv (in the range of annual dose of natural radiation)
- Some exams (cardiac with thallium , abscess with gallium) deliver higher doses and should be only undertaken when other modalities are inappropriate

Radionuclide dose calibrator

- Re-enterent ionization chamber that is used to check the activity of radionuclide vial before patient administration
- Ionization current is dependant on
  - Activity of the sample
  - Sensitivity of the chamber to the energy of the gamma rays assessed
  - Geometry of the source within the calibrator
    - Thus radionuclide and syringe type must be selected on the control panel
- accuracy of the calibrator is checked regularly using a long lived source (Co-57)
- Used also to measure radionuclide purity

Measures to decrease patient dose

- Patient should drink good deal of water and empty the bladder frequently (reduce dose to gonads)
- Females should avoid conception for an appropriate period following administration of long lived tracers ($t_{1/2} > 7$ds)
- females who are or may be pregnant should avoid examinations which will result in fetal dose > 10 mSv
- Interruption of breast feeding is recommended after exam
- Patient's identity must be checked against type of study and the activity to be administered

Radionuclide handling precautions

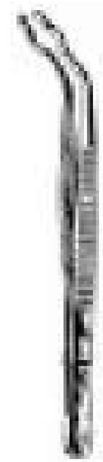
- Types of hazards to staff while handling tracers
  - External radiation
  - Internal radiation: accidental ingestion or inhalation of radionuclide or its entry through a wound
- Precautions include segregation and personal protection

Segregation:

- There must be separate areas for
  - Preparation and storage of radioactive materials
  - Injections of patients
  - Patient’s waiting (should be spaced apart in the waiting area… why?)
  - Imaging
  - Temporary storage of radioactive waste

Personal protection:

- Staff should enter radioactivity areas only when it is strictly necessary
- Radionuclide should be contained in shielded generators or bottles inside lead pots
- Syringes are handled with long handled forceps, and protected by tungsten or lead glass sleeves (decrease finger dose by 75%)
- Syringes are carried to the patient into a special container
- Labeling of pharmaceuticals should be carried out with the arms behind a lead barrier and over a tray lined with absorbent paper
- Before injection, syringes are vented into swabs or closed containers
- Staff is monitored for external radiation doses

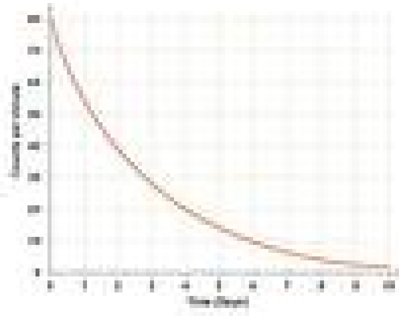


- Waterproof surgical gloves are worn when handling tracer
- Abrasions must be covered
- No eating or drinking inside the room
- Hands and work surfaces are routinely monitored for radioactive contamination
- Air in the room must be sampled And monitored
- Staff is monitored for internal contamination
- If there is slight spillage → decontamination by water , mild detergents and swabs (sealed in plastic begs and disposed as radioactive waste)
- If contamination is obstinate → special detergent solutions
- Hands is washed regularly at special hands free designated washbasins

N.B: lead rubber aprons are ineffective against high energy gamma radiation

Dealing with radioactive spill

- Clear area from non essential persons
- Wear gloves aprons and overshoes
- Mop the floor with absorbent pads and seal swabs as radioactive waste
- Continue until monitoring show the activity to be satisfactorily of low level
- If necessary cordon off the area or cover it with impervious sheeting until sufficient decay has occurred



Disposal of radioactive waste

principles:

- Containment and decay
- Dilution by dispersal to the environment

Roots:

- Disposal of gaseous waste:
  - Ventilation to atmosphere
  - Used with wastes of lung ventilation studies
    - Xe-133 & Tc-99m aerosols: to the exterior of the building
    - Kr-81m (very short t½): Ventilation to exterior is desirable but not always necessary (adequate room ventilation is a must)

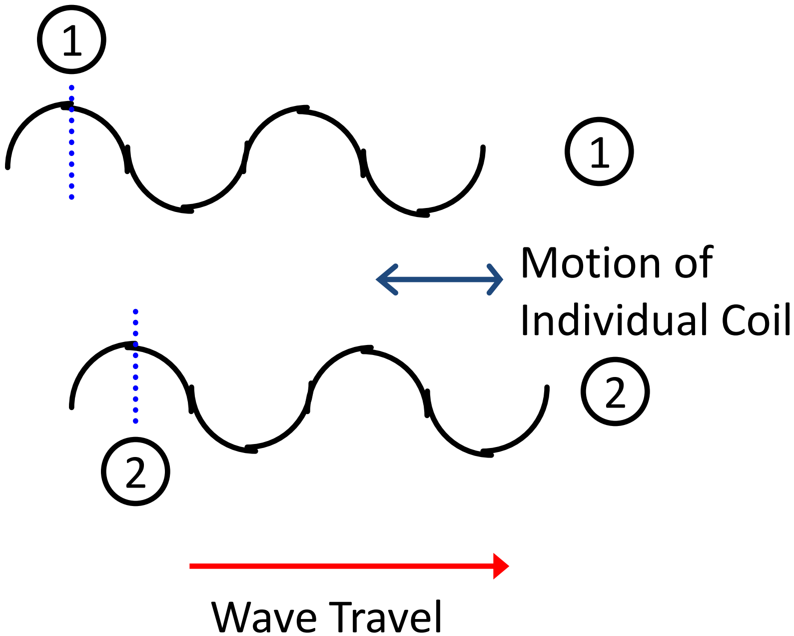
- Disposal of liquid waste:
  - Well diluted with water via designated sinks draining into foul drains (as long as levels are within authorized levels)
- Disposal of solid waste (swabs ,syringes and bottles):
  - Placed into designated sacs for disposal in:
    - authorized incinerators
    - With ordinary waste if suitably diluted
  - Used generators are kept in a secure shielded store until returned to manufacturer
  - Contaminated clothing; stored in protected area until the activity is sufficiently decayed , then released to laundry

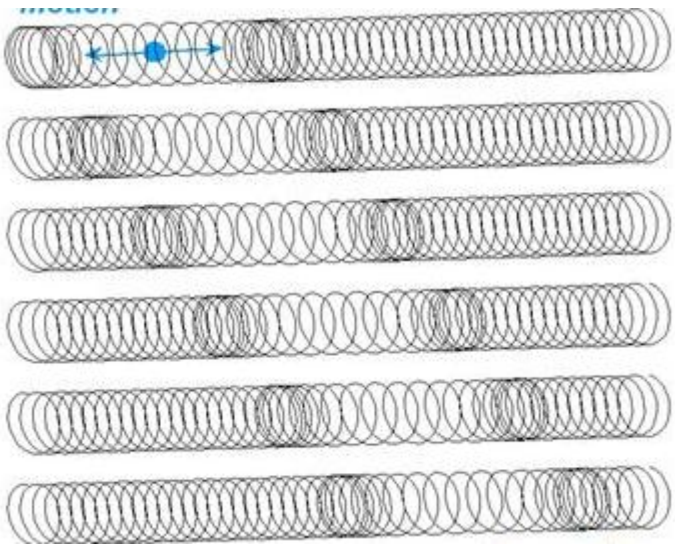
Ultrasound physics

Sound Properties and Parameters

Sound waves is Longitudinal Waves

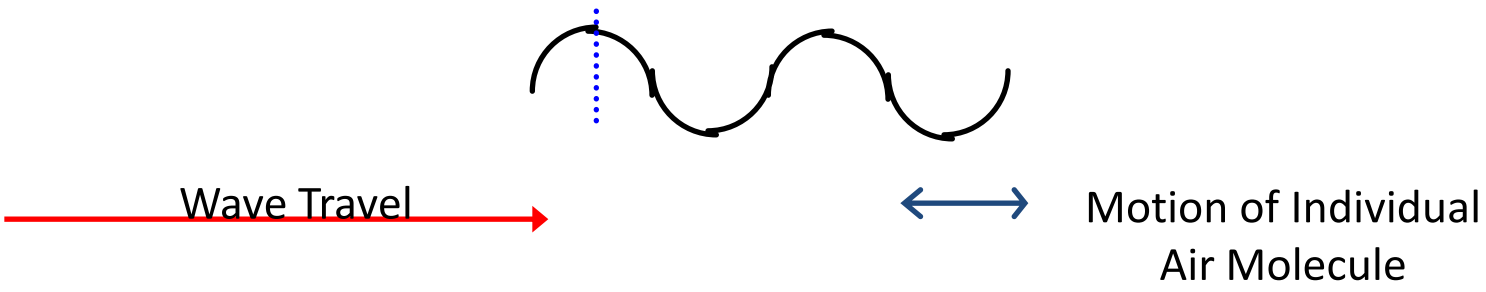
i.e. Particle motion <u>parallel</u> to direction of wave travel



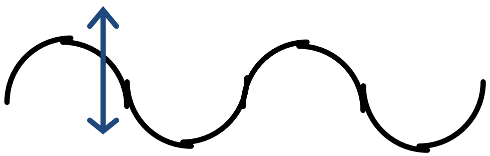


Sound Waves are Compression Waves

- Regions of alternating low and high pressure move through air
- Particles oscillate back & forth parallel to direction of sound travel

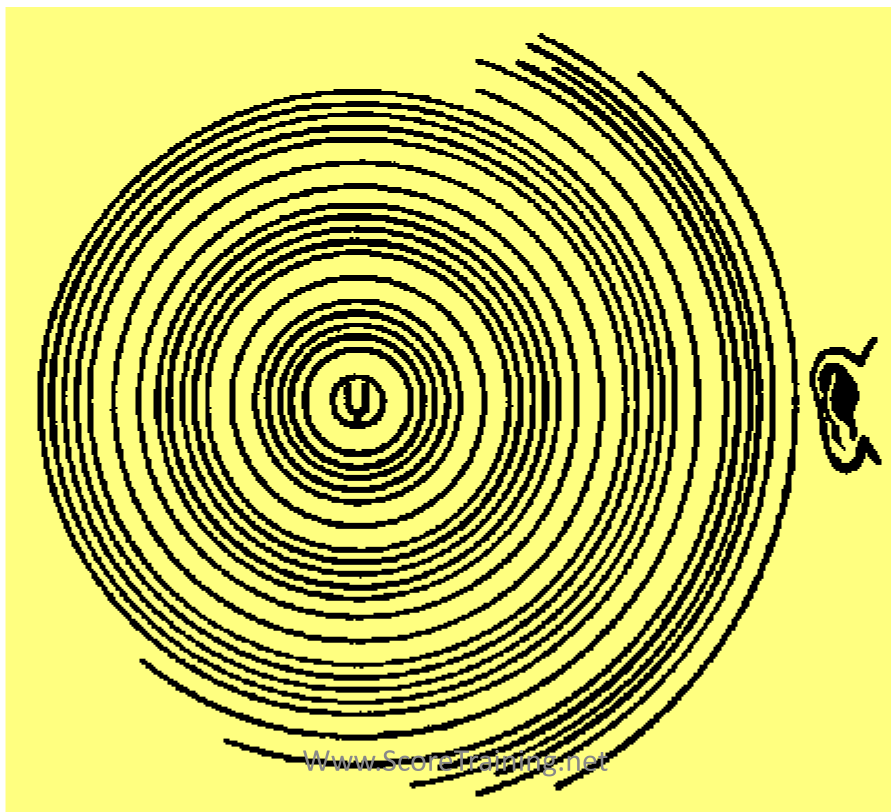


- N.B. In Transverse Waves:
  - Particle moves perpendicular to wave travel
  - Example: Electromagnetic waves



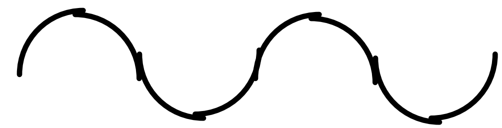
Medium

- medium is required for sound
  - sound does not travel through vacuum
- Medium not required for electromagnetic waves



Sound Frequency

of complete cycles of sound waves per unit time



- Units

  cycles per second

  1 **Hz** = 1 cycle per second

  1 **kHz** = 1000 cycles per second

  1 **MHz** = 1,000,000 cycles per second

- Human hearing range

  20 - 20,000 Hz

  sound frequency corresponds to pitch

Sound Frequency

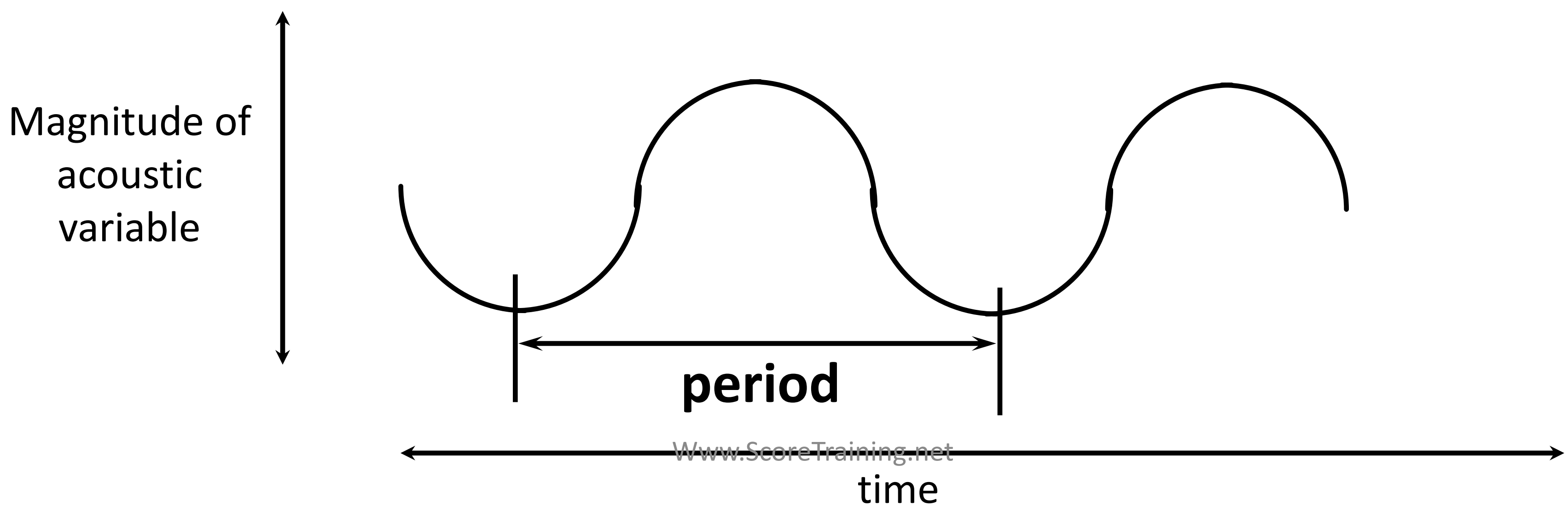
- Ultrasound definition
  > 20,000 Hz
  – not audible to humans
- Clinical ultrasound frequency range
  1 - 10 MHz
  1,000,000 - 10,000,000 Hz

Period

- Time between a given point in one cycle & the same point in the next cycle (time of single cycle)

$$\text{Period} = \frac{1}{\text{Frequency}}$$

- As frequency increases, period decreases
- Sound Period & Frequency are determined only by the sound source. They are independent of medium



Period = 1 / Frequency

- if frequency in Hz, period in seconds/cycle
- if frequency in kHz, period in msec/cycle
- if frequency in MHz, period in μsec/cycle

If frequency = 2 **MHz** then sound period is 1/2 = 0.5 **μsec**

If frequency = 10 **kHz** then sound period is 1/10 = 0.1 **msec**

If frequency = 50 **Hz** then sound period is 1/50 = 0.02 **sec**

Sound Speed

- *Speed is only a function of medium*
- Speed is dependant on material through which it travels
- Speed is (nearly) constant for a given material (independent on frequency)
- Material properties affecting sound velocity:
  - Density: ↑density →↓velocity
  - Compressibility: ↑ Compressibility (or ↓ elastic modulus) →↓velocity
- Notes:
  - Velocity also depends on temperature
  - soft tissues sound take 7 µsec to travel for 1 cm (1.54mm/ µsec)

Acoustic Impedance (Z)

- Definition

$$\boxed{\text{Acoustic Impedance = Density X Prop. Speed}}$$

Material	Velocity (m/s)	Density	Acoustic impedance (Z)
Air	330	1.29	430
Soft tissue	1540	1000	$1.5X10^{6}$
Bone	3200	1650	$5.3x\ 10^{6}$
PZT	4000	7500	$30\ x10^{6}$

Note that:

•Air sound velocity is ↓ despite having↓ density (because it has ↑ compressibility)

•Frequency of ultrasound in different media is constant (= frequency of transducer) , so that changes in velocity from one medium to another will change ……………..

•acoustic impedance is independent of frequency

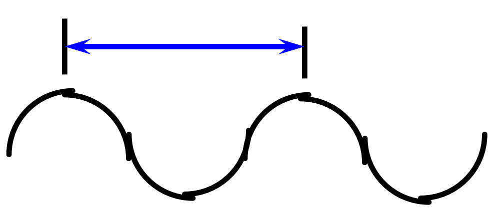
•Differences in acoustic impedance determine fraction of ultrasound echoed at an interface

Wavelength

- *distance <u>in space</u> over which single cycle occurs*

= distance between a given point in a cycle & corresponding point in next cycle

- Unit = length per cycle
- usually in millimeters or fractions of a millimeter for clinical ultrasound



Wavelength Equation

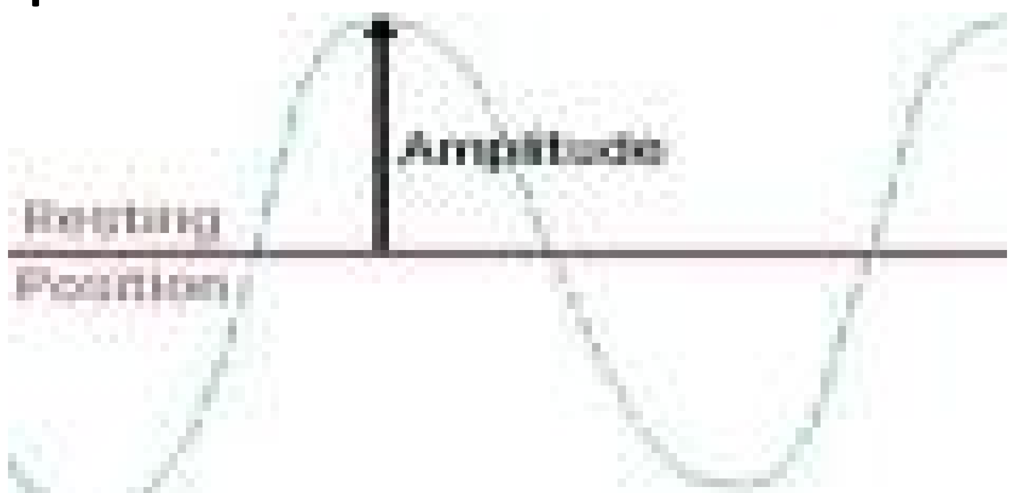
Speed = $\boxed{\text{Wavelength X Frequency} \quad [\, c = \lambda \times \nu \,]}$

(dist./time) (dist./cycle) (cycles/time)

- As frequency increases, wavelength decreases
  - because speed is constant
- Wavelength is a function of both the sound source <u>and</u> the medium! (why?)

Sound intensity

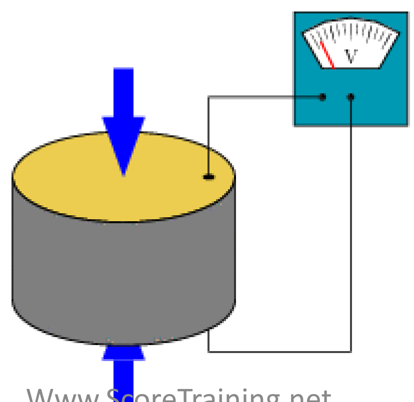
- Quantity of ultrasound
- Unit = Watts/mm^2
- Proportional to square of wave amplitude
- Under operator control



Note:
Ultrasound can undergo reflection ,refraction and focusing (unlike X & γ rays)

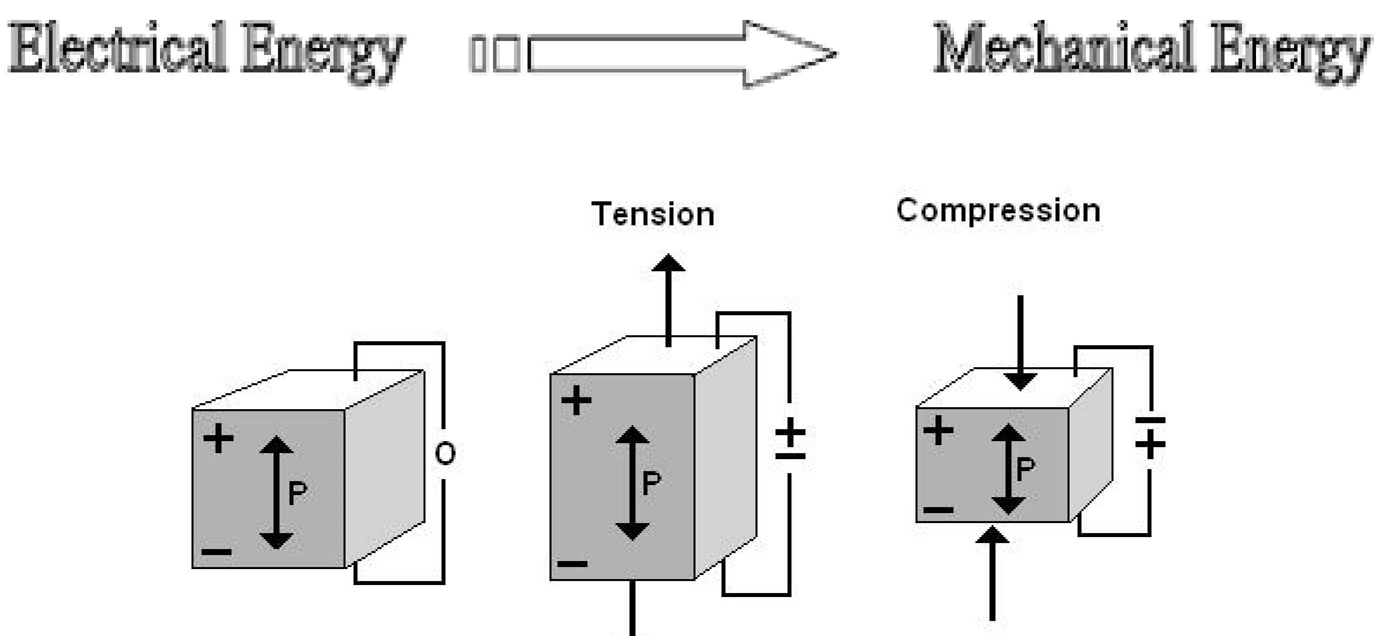
Piezoelectric effect

- Definition:
  - conversion of electrical signals to mechanical energy (ultrasound beam) and vice versa
- Uses: **ultrasound transducer**
  - Made of piezoceramic disc that consists of either:
    - compressed microcrystalline lead zirconate titanate (PZT)
    - Or plastic polyvinylidine difluoride (PVDF)
  - Two flat faces of the disc is made electrically conducting with a very thin coating of silver



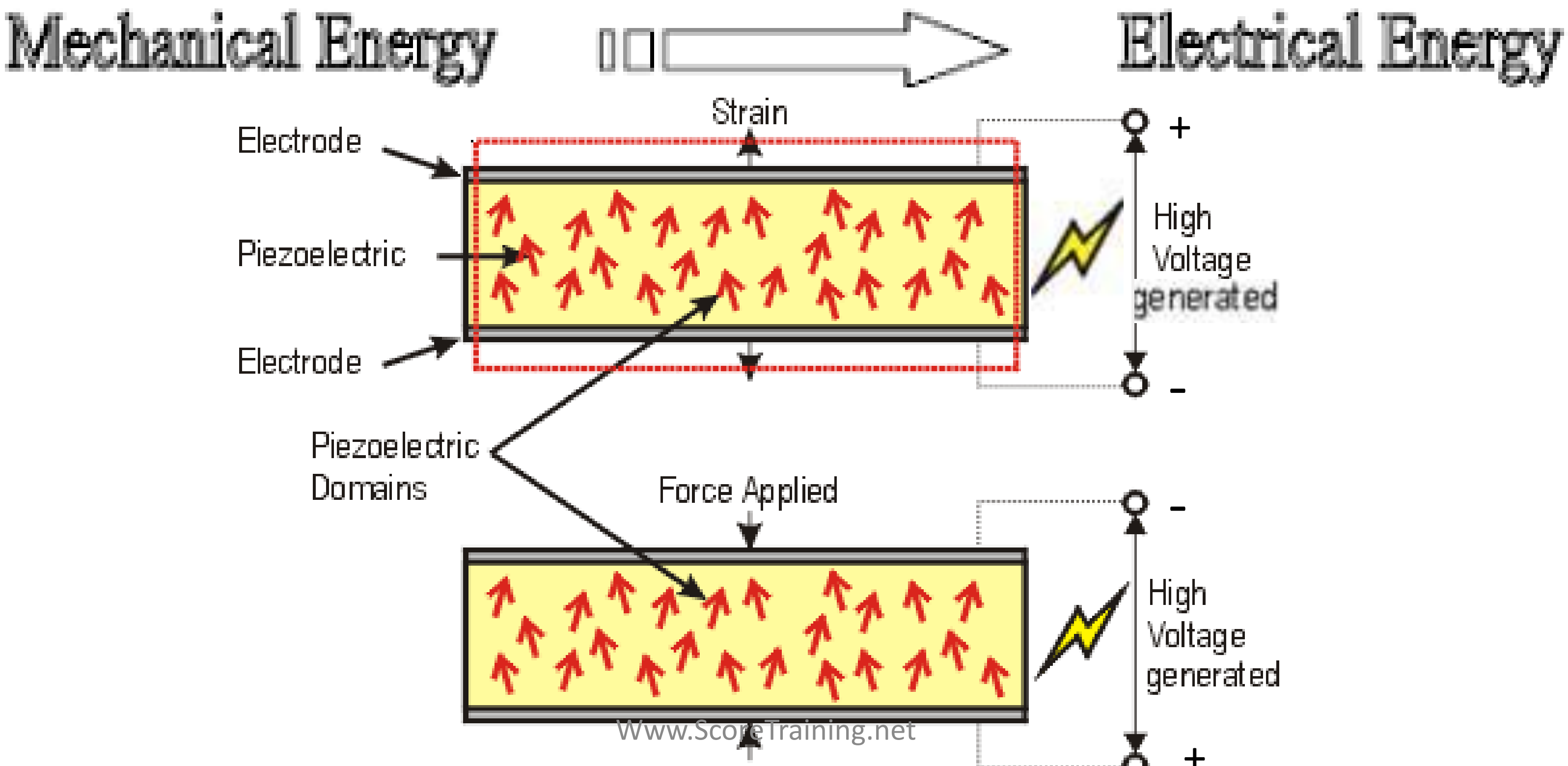
DC application to the piezoceramic disc:

- DC voltage is applied to the flat faces of the disc → it expands
- If the voltage is reversed → it contracts
- The movement of the faces is proportional to the voltage



The reverse is also possible:

- If disc is compressed → voltage is generated
- If pressure is reversed → voltage is reversed
- Voltage produced is proportional to the pressure applied



AC application to the piezoceramic disc:

- Disc will alternately expands and contracts with the same frequency of the AC→ production of sound waves
- also: When the disc is subjected to alternating pressure , an alternating voltage is produced of the same frequency → receiving of sound waves
- This means that: The same transducer can act as transmitter and receiver of the sound

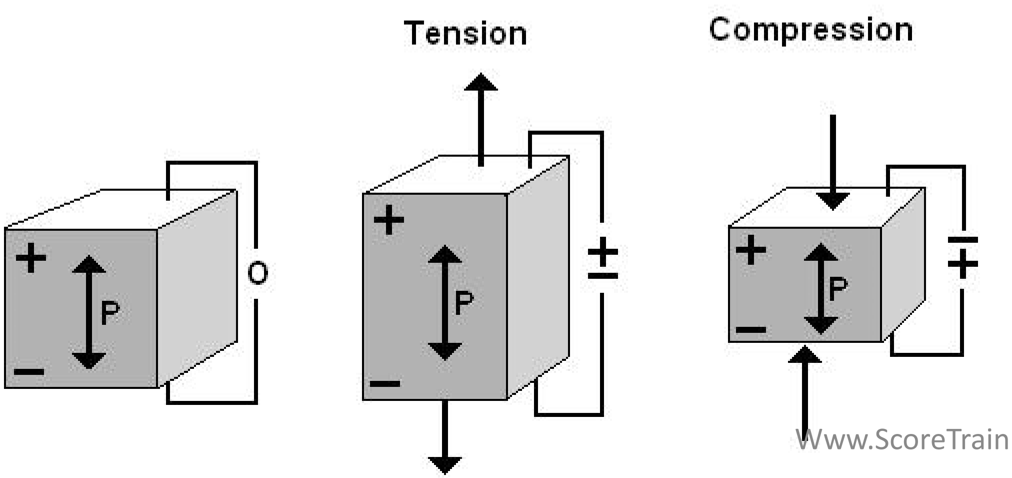
Notes:

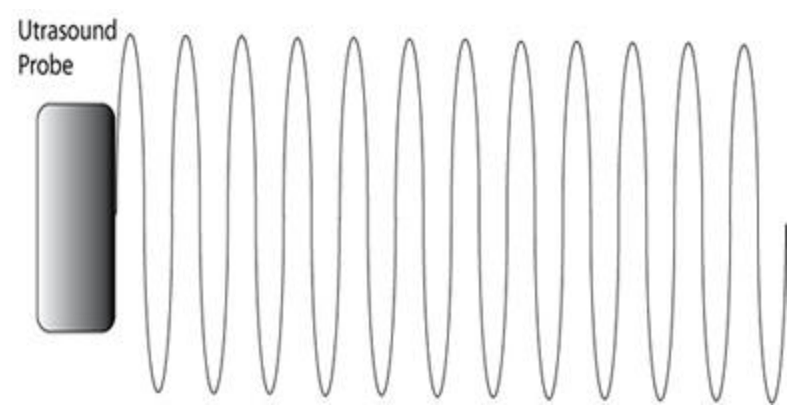
- Curie temperature: temperature above which transducer lose its piezoelectric properties
- Transducer should not be autoclaved
- Thin slices of naturally occurring quartz crystals also show piezoelectric effects (used in digital timers)

Continuous and pulsed Ultrasound

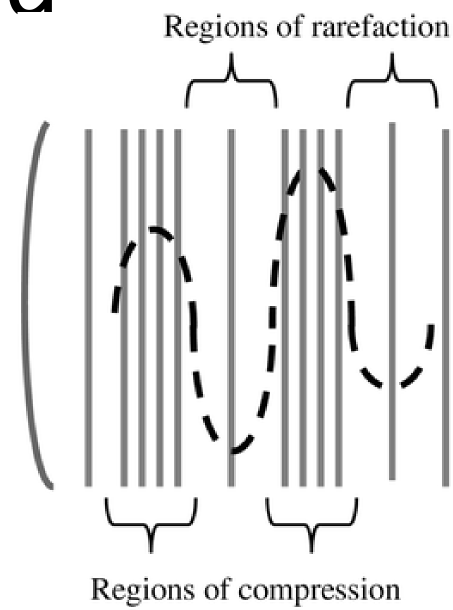
Continuous mode ultrasound

- AC voltage is applied to the crystal
- The crystal face pulses forward & backwards (through distance <1µm), producing successive compressions & rarefactions waves
- Density (& pressure) of the material rise & fall above its normal atmospheric value (can reach several atmospheres)
- Frequency with which compression waves pass through material = frequency of AC voltage applied = frequency of ultrasound produced

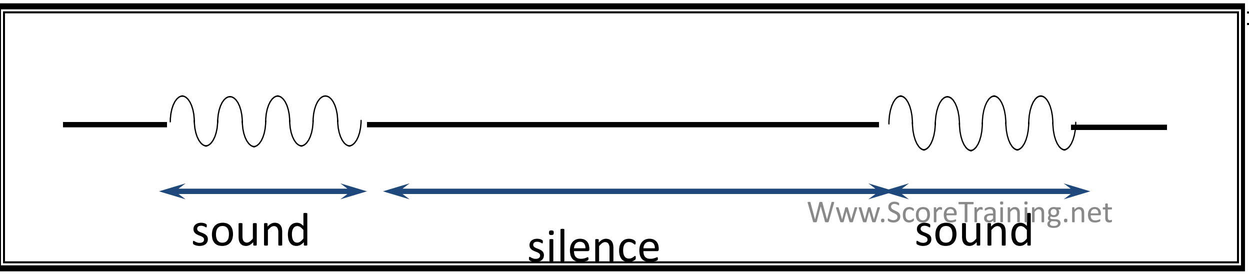


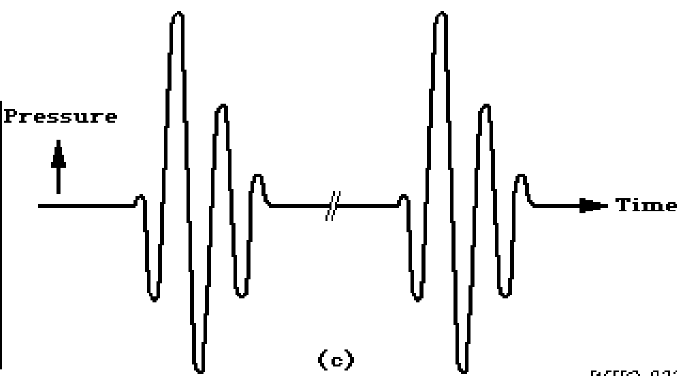


Pulse Mode Ultrasound



- Few hundred volts **DC** are suddenly applied to the disc
- It expands , compressing a layer of material in contact with it
- The compressed layer then expands compressing layer of the material in contact with it
- So that: wave of compression travels with velocity (v) through the material followed by corresponding wave of decompression
- Short regular sound pulses are produced
- Every pulse produce spectrum of frequencies (compare to continuous mode)





So that

•Sound is Pulsed on & off

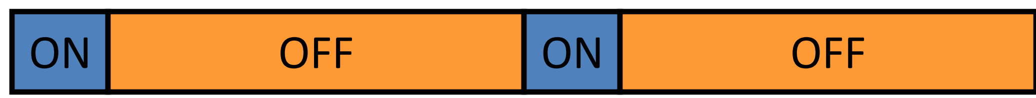
On Cycle (speak)

Transducer produces short duration sound

Off Cycle (listen) = dead time

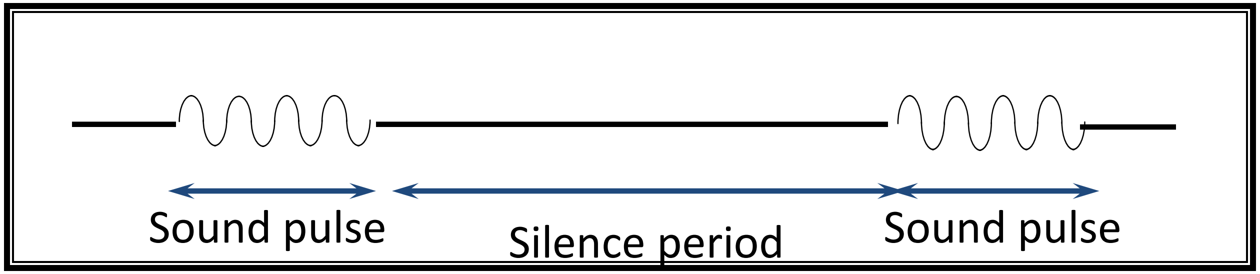
Transducer receives echoes

longer duration



This means that the same transducer used for

- transmitting sound
- receiving echoes



- one pulse cycle =
  - one sound pulse
    and
    one period of silence

- The ultrasound frequency is dependant on the transducer material (= resonant frequency) not on the current applied (compare to continuous mode)

Parameters of pulsed ultrasound

- pulse repetition frequency
- pulse repetition period
- pulse duration
- duty factor
- spatial pulse length
- cycles per pulse

Pulse Repetition Frequency

- Number of sound pulses per unit time

= number of times ultrasound beam turned on & off per unit time

≠ sound frequency

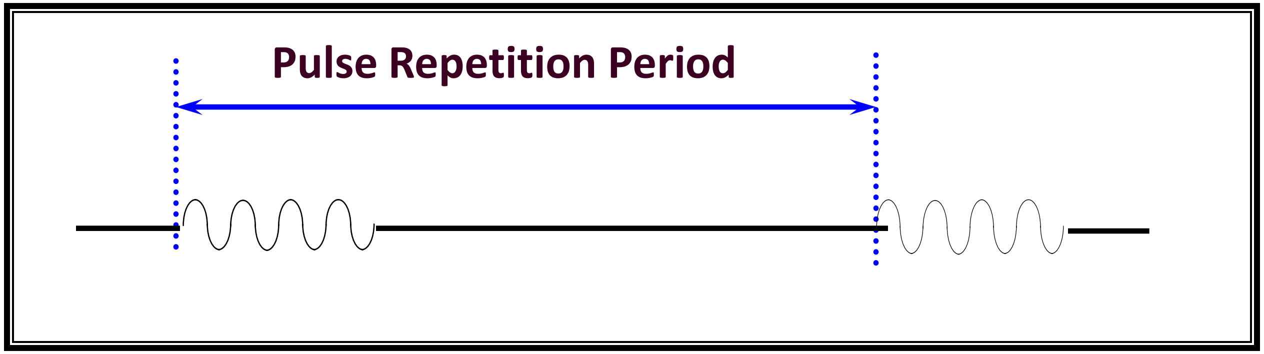
- determined by the source (the scanner) (= frequency of applied voltage pulses)

- clinical range (typical values)
  - 1 - 10 KHz

Pulse Repetition Period

- time from beginning of one pulse until beginning of next

= time between corresponding points of adjacent pulses



Pulse Repetition Period

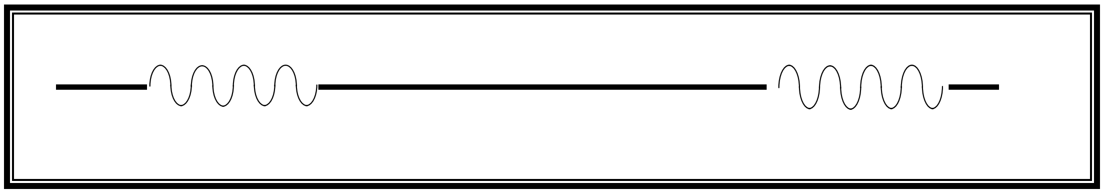
- Pulse repetition period is reciprocal of pulse repetition frequency

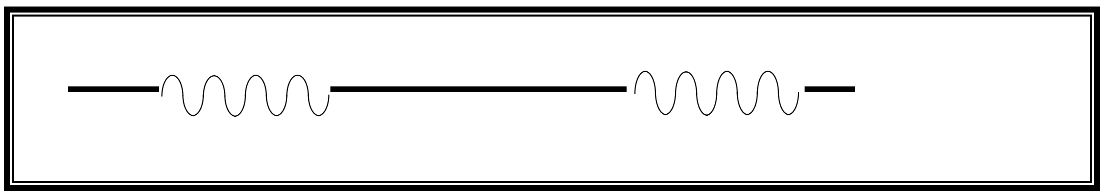
$$\boxed{PRF = 1 / PRP}$$

  - as pulse repetition frequency increases, pulse repetition period decreases

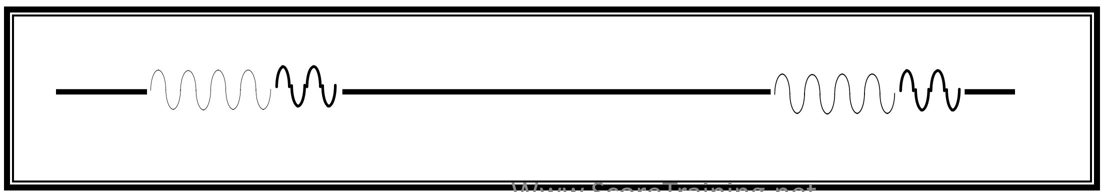
- pulse repetition period & frequency determined by **source**

- Pulse repetition frequency & period independent sound frequency & period





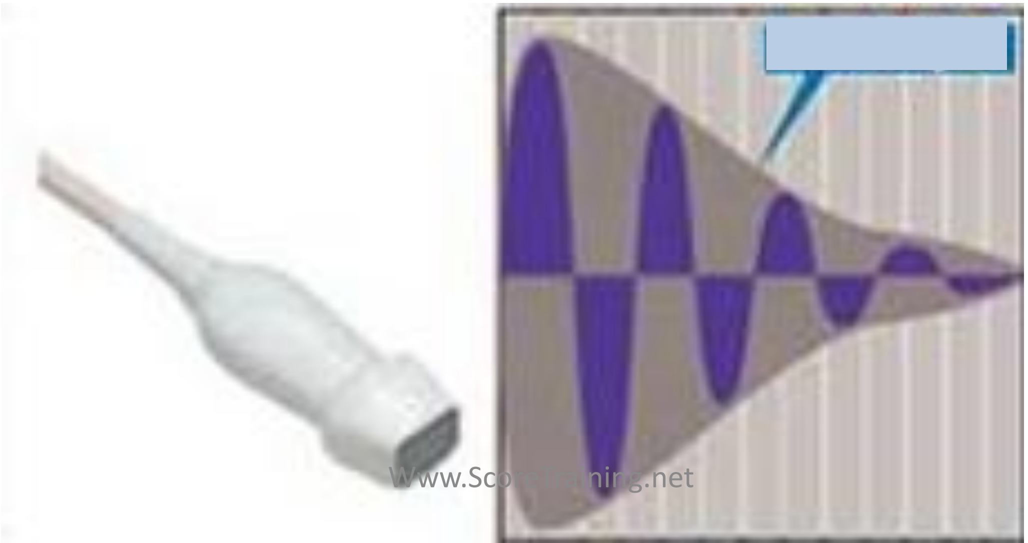
Same sound Frequency
Higher Pulse
Repetition Frequency



Higher sound Frequency
Same Pulse
Repetition Frequency

Pulse Duration

- When transducer is pulsed → it continues to vibrate for a short while with diminishing amplitude as it lose energy
- Pulse Duration= Length of time for each **sound pulse**
- units
  - time per pulse



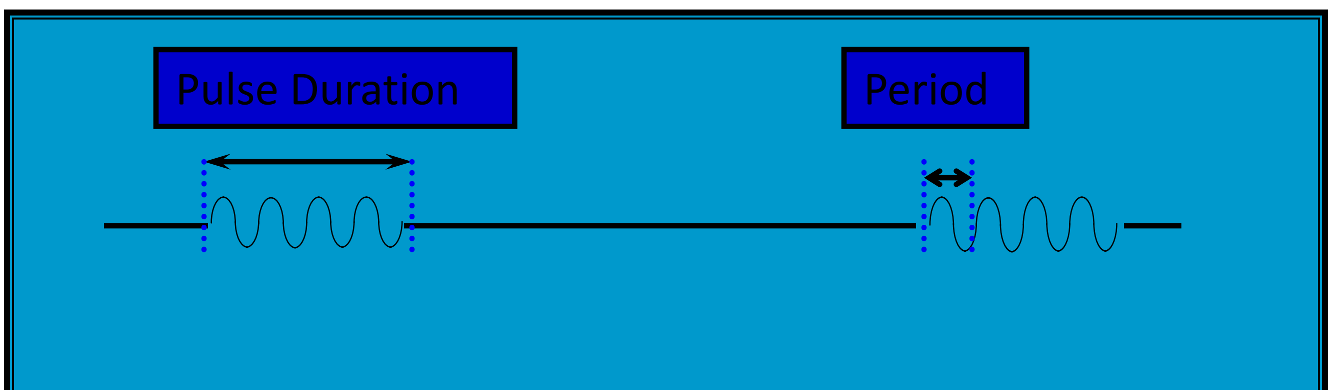
Pulse Duration

- equation

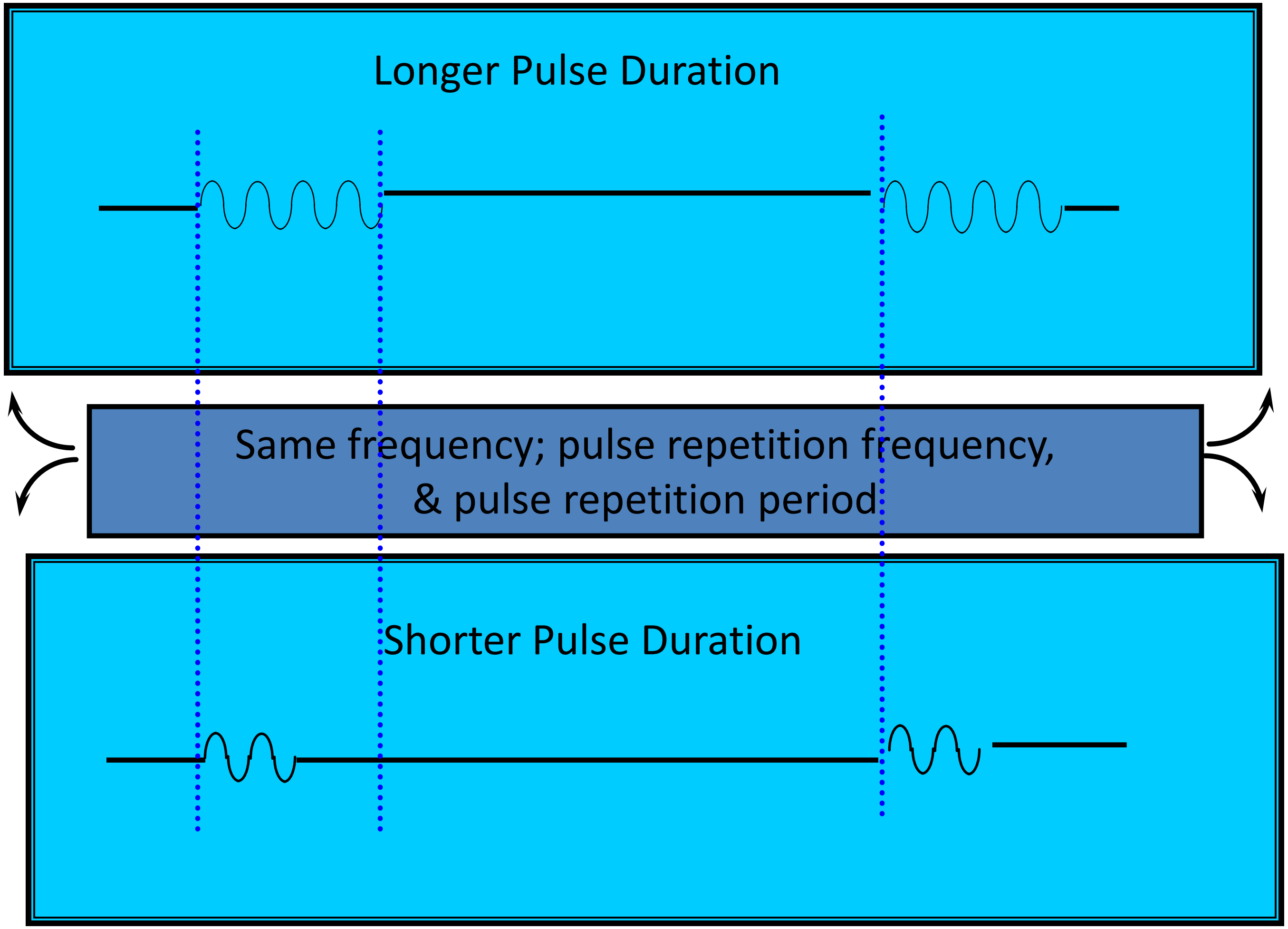
$$\boxed{\text{pulse duration} = \text{sound Period X \# sound cycles per pulse}}$$

(time/pulse) (time/cycle) (cycles/pulse)

- typically 2-3 cycles per pulse (3 x t)



Pulse Duration



Number of sound cycles/pulse is changed

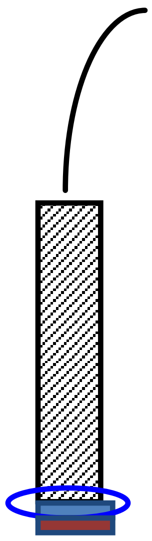
Pulse Duration

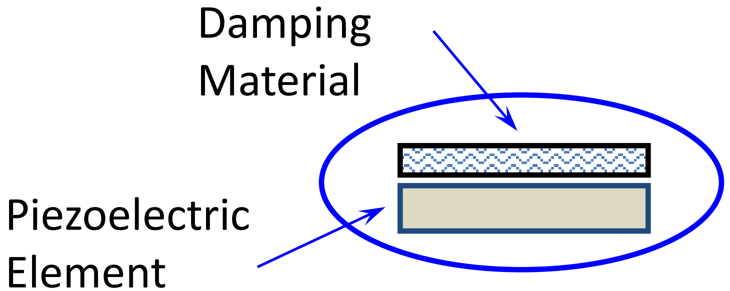
- Pulse duration (ring down time) is a controlled by the sound source

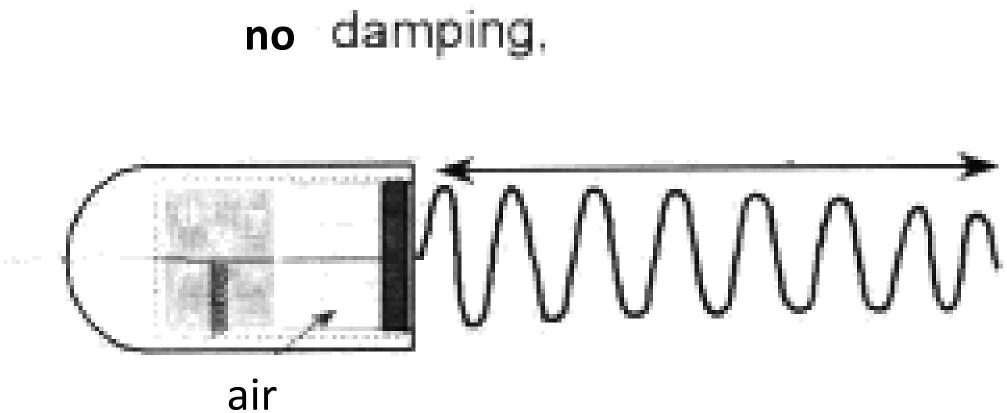
- Transducer tends to continue ringing
  – This is minimized by **dampening** transducer element

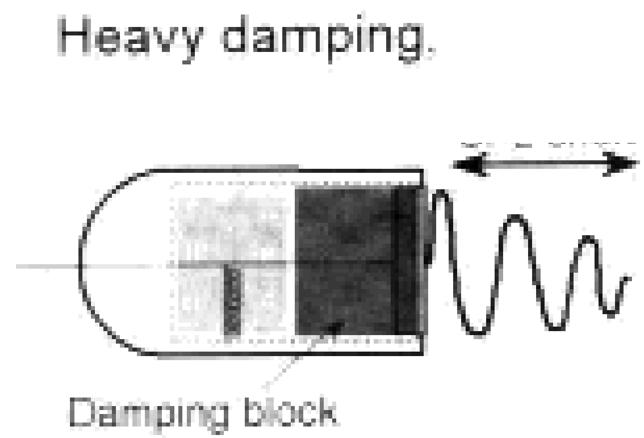
Damping Material

- Goal:
  - reduce cycles / pulse by damping out vibrations after voltage pulse "ring-down"
- Place:
  - attached to near face of piezoelectric element (away from patient)







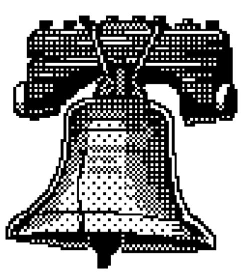


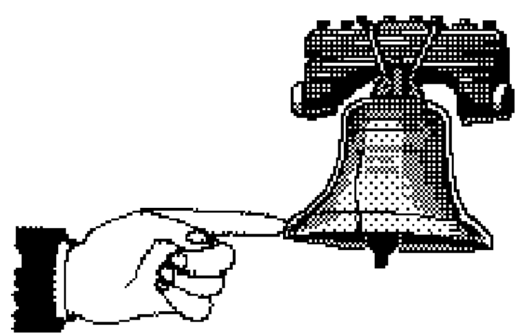
N.B: if the block is omitted (disc is packed with air) → the pulse will last for 20 or more periods

N.B: Additional damping may be performed electronically by applying a second reverse voltage pulse very shortly after the first

Disadvantages of Damping

- Reduces beam intensity
- produces less pure frequency (tone)
  - the shorter the pulse, the higher the range of frequencies produced
  - Range of frequencies produced called **bandwidth**

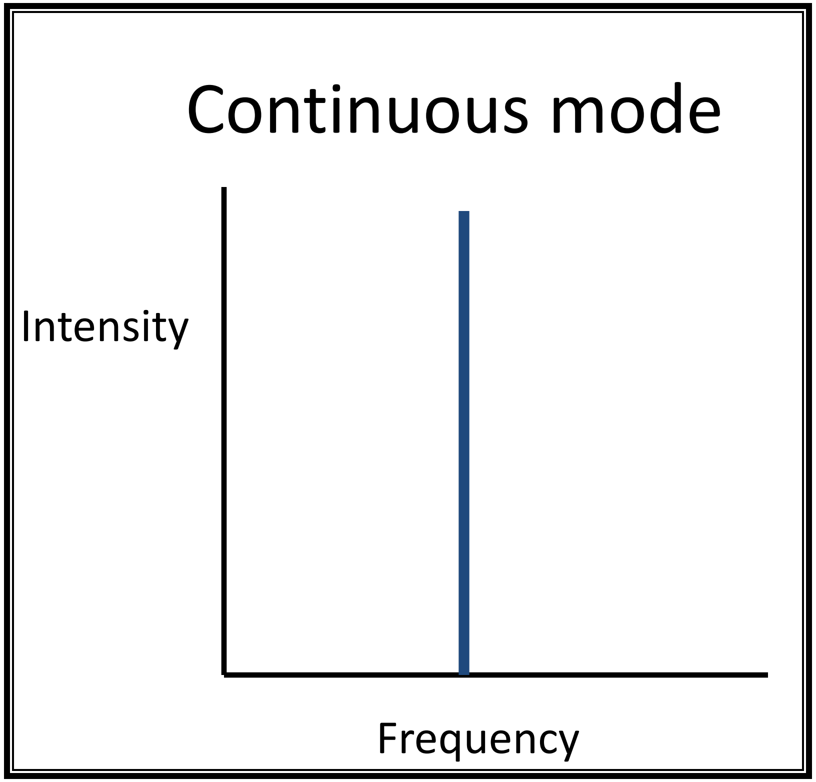


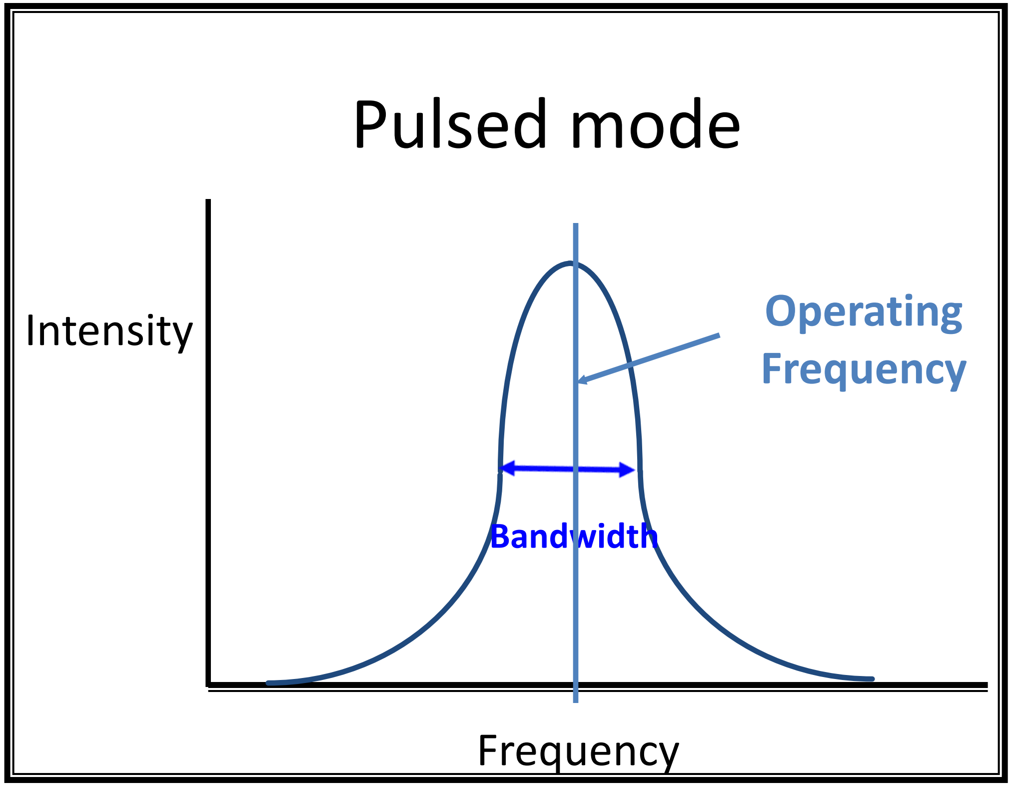


Bandwidth

- range of frequencies present in an ultrasound pulse

=FWHM of frequency spectrum



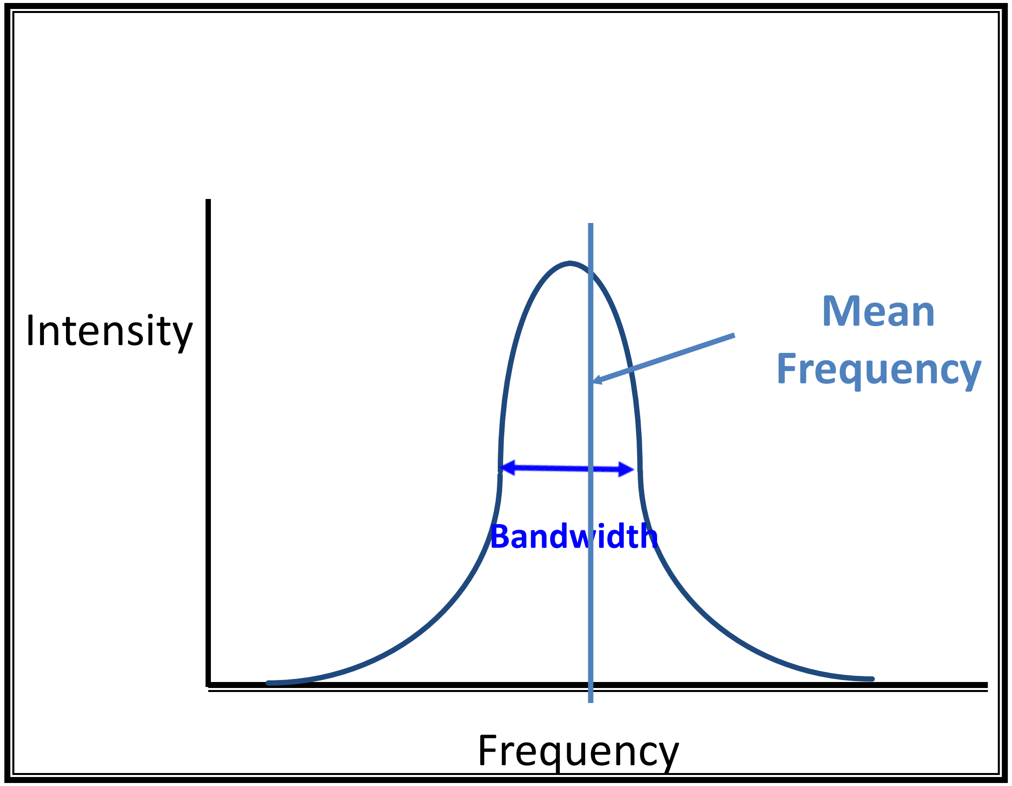


Frequency = ...

Quality Factor ("Q") = mechanical coefficient

$$\text{Quality Factor} = \frac{\text{mean (resonance)frequency}}{\text{bandwidth}}$$

Q is a Quantitative Measure of "Spectral Purity" (↑Q→ narrower bandwidth)

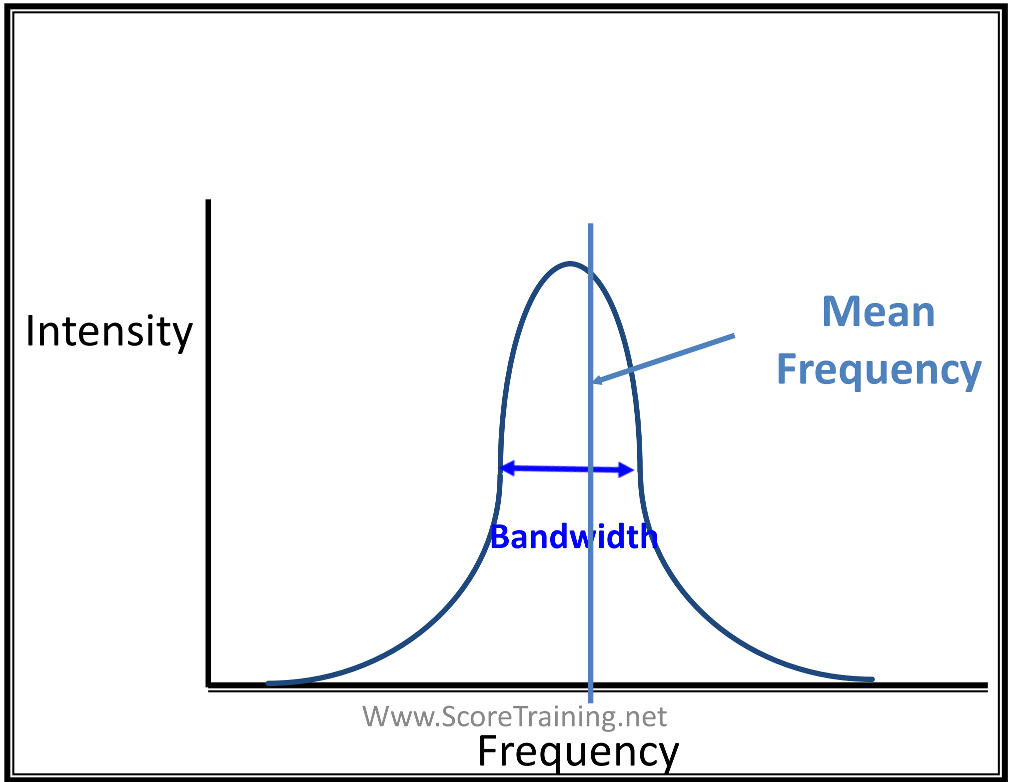


- N.B: Same graphs represent the resonance curve

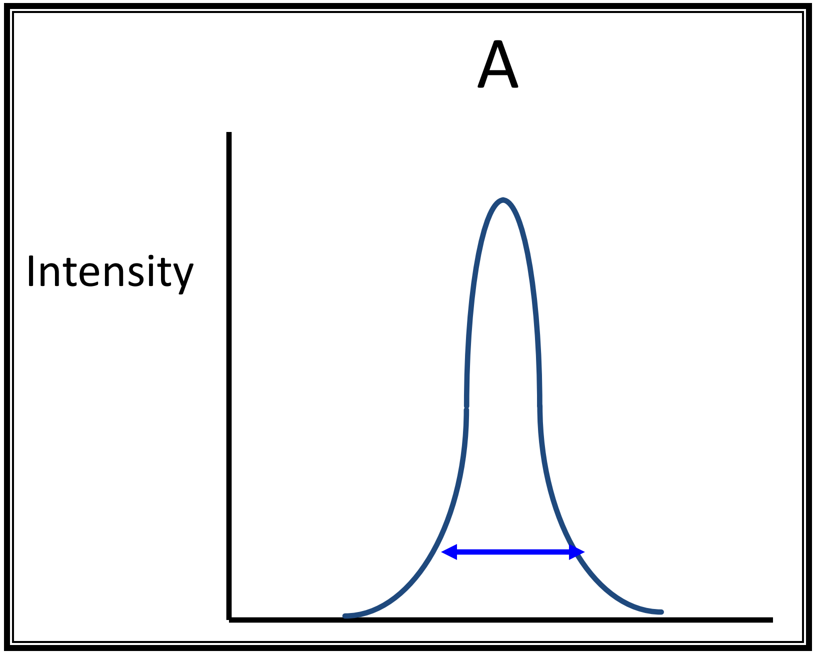
  i.e. the response of the transducer as a receiver to waves of different frequencies

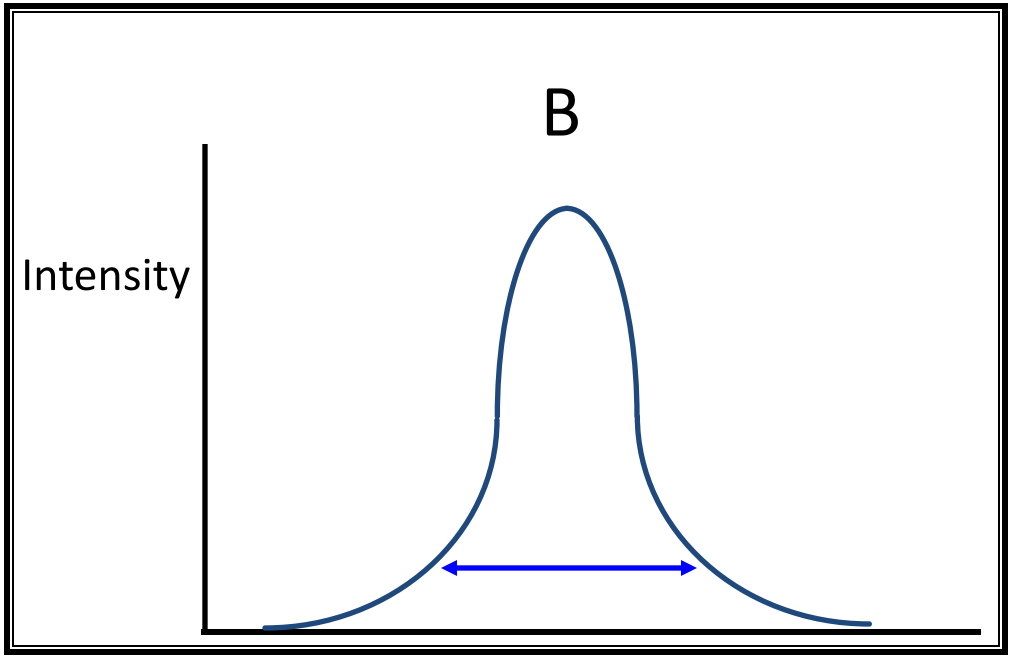
  i.e. transducer with ↑Q produce a pure note and respond only to that note

- Compare between pulsed and continuous ultrasound according to Q & received frequencies



Which has a Higher Quality Factor?
Which have less pulse duration?
Which have less damping?





Frequency

Same Operating Frequency!

Frequency

Conclusion

- More damping results in
  - shorter pulses
  - more frequencies
  - higher bandwidth
  - lower quality factor
  - lower intensity

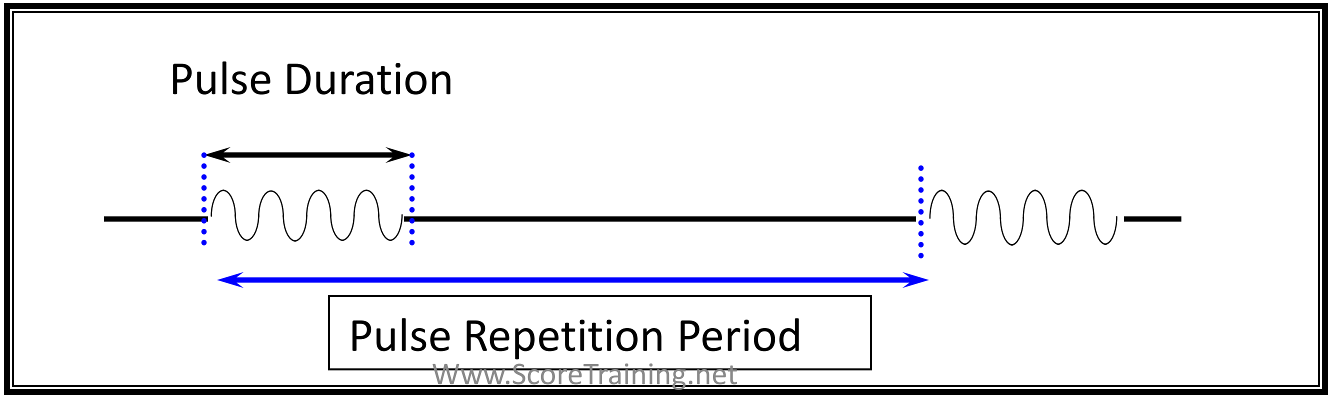
Duty Factor

- Fraction of time sound generated
- Determined by source

- Equations

$$\boxed{\text{Duty Factor} = \text{Pulse Duration} / \text{Pulse Repetition Period}}$$

$$\boxed{\text{Duty Factor} = \text{Pulse Duration X Pulse Repetition Freq.}}$$



Spatial Pulse Length

- distance in space traveled by ultrasound during one pulse

Spat. Pulse Length = # sound cycles per pulse X wavelength

(dist. / pulse) (cycles / pulse) (dist. / cycle)

- depends on source & medium (why?)

Spatial Pulse Length

Spat. Pulse Length = # cycles per pulse X wavelength

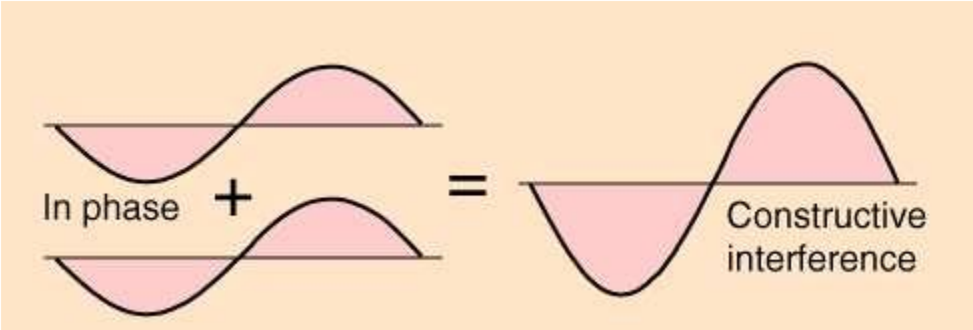
Wavelength = Speed / Frequency

- as wavelength increases, spatial pulse length………
- as # cycles per pulse increases, spatial pulse length ………
- as frequency increases spatial pulse length ……….
- *Spatial pulse length determines axial resolution (see later)*
- Spat. Pulse Length = 3 λ or less

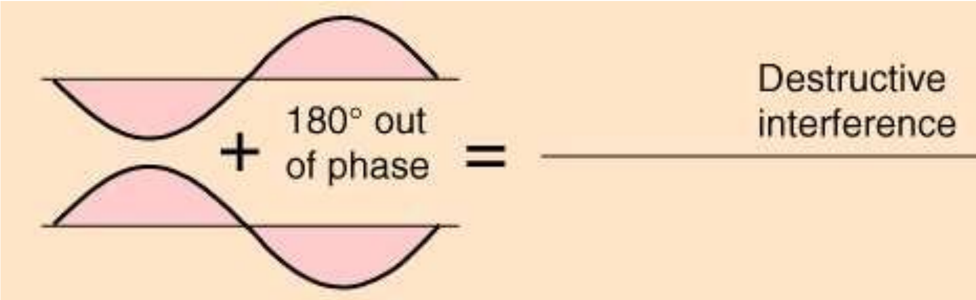
Sound interference

If two sound waves of the **same wavelength** cross each other , the pressure waves combine

- If they are exactly in-phase → their amplitudes add up



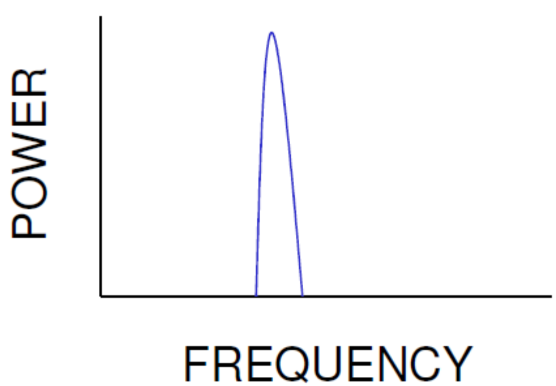
- If they are exactly out of phase → reduced intensity



Ultrasound Resonant Frequency

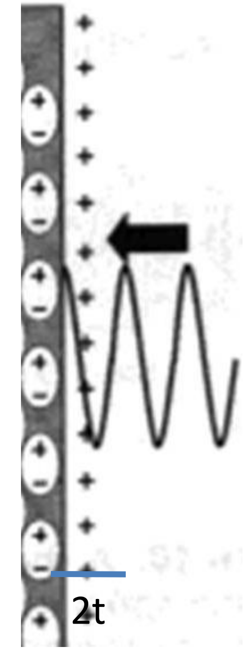
- Frequency at which the transducer vibrates most violently and produce largest output of sound (AC)
- Frequency at which transducer is most sensitive as receiver
- Resonant Frequency at which the transducer vibrate when given DC pulse

= frequency which produce wave length = 2 x transducer thickness

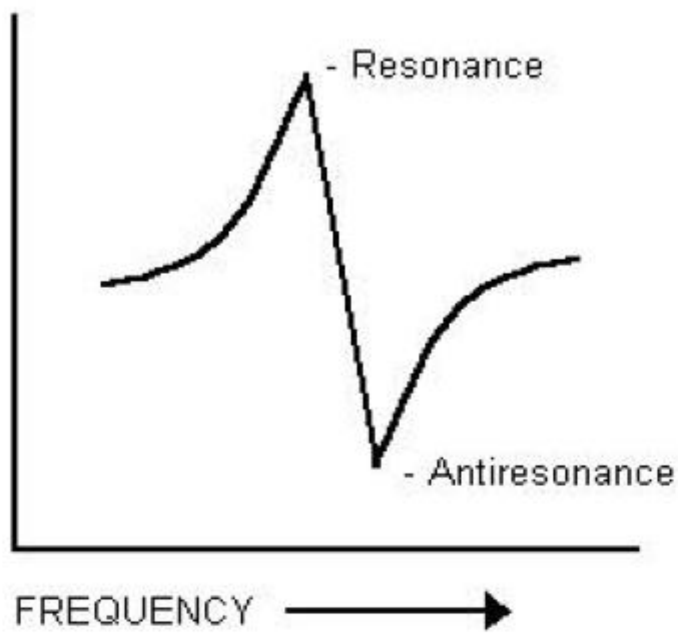


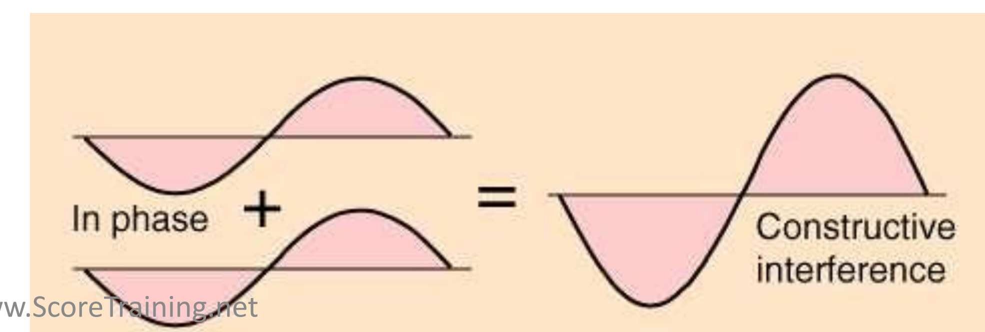
Explanation of resonant frequency

- Front face of the transducer emits sound in both the forwards and the back direction
- The back-wave is reflected at the back face of the disc
- By the time it joins the front wave , it has traveled distance = 2t →both are exactly in phase → constructive interference
- If ultrasound frequency changes → some destructive interference will occur



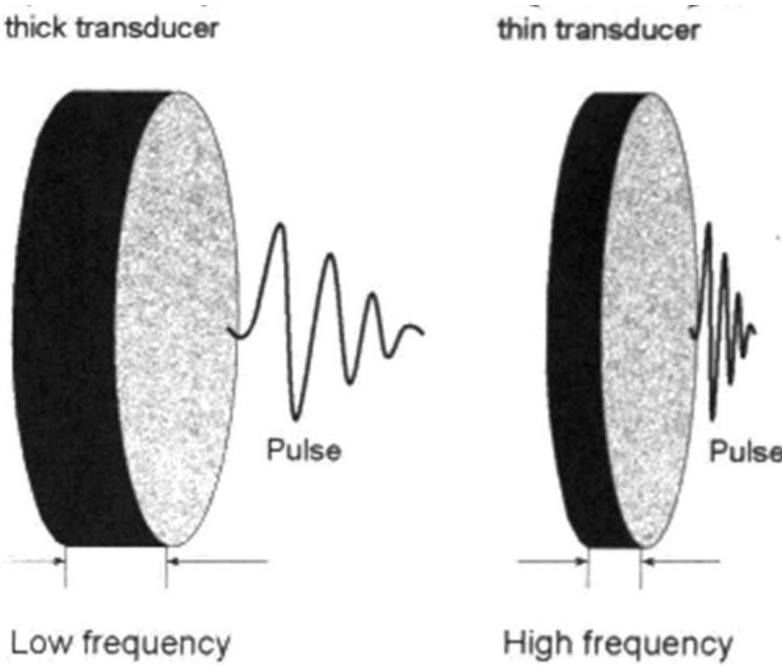
t





Notes:

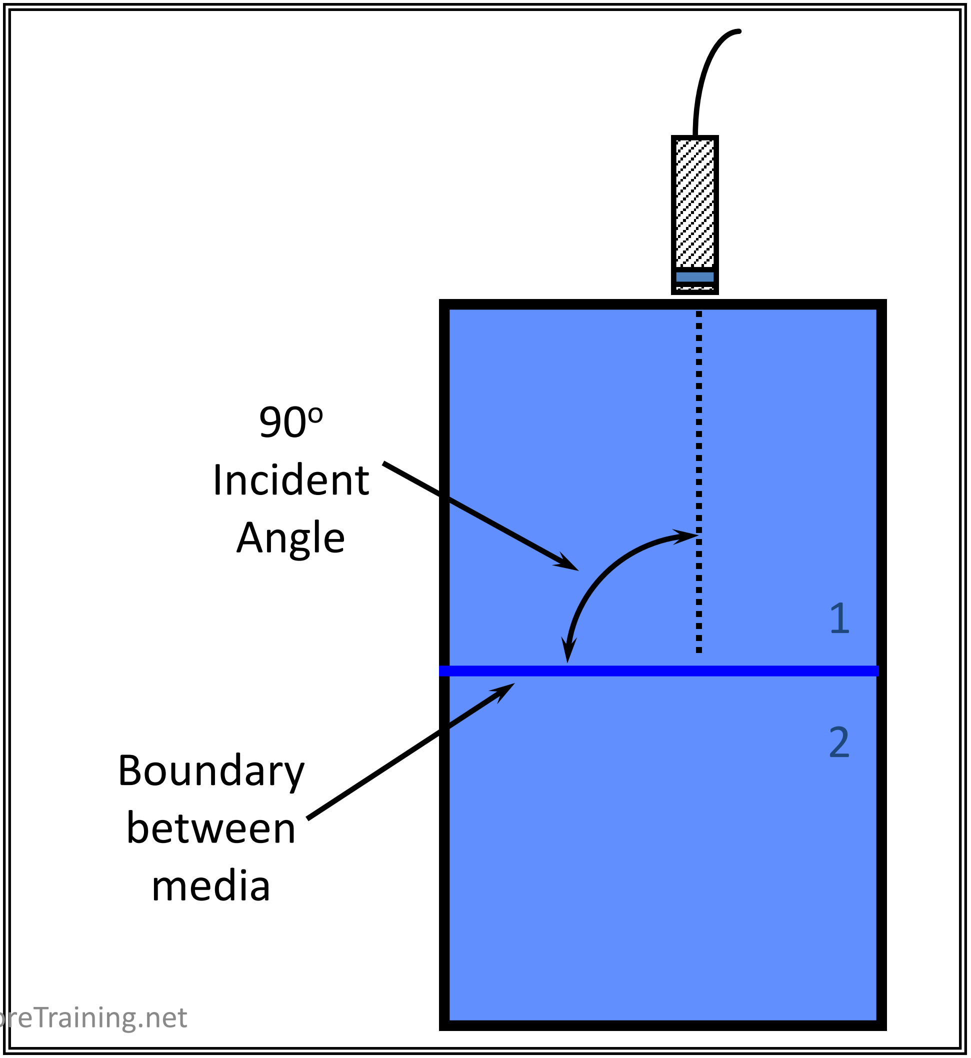
- Resonant Frequency is the frequency at which the transducer vibrate when given DC pulse , other frequencies produced die away quickly because of the destructive interference (what happens if we apply AC?)
- The thicker the transducer , the lower is the natural frequency
- Natural period = 1/f at λ = 2t
- A 3.5 MHz transducer has disc of about 0.5 mm thick



Ultrasound Reflection

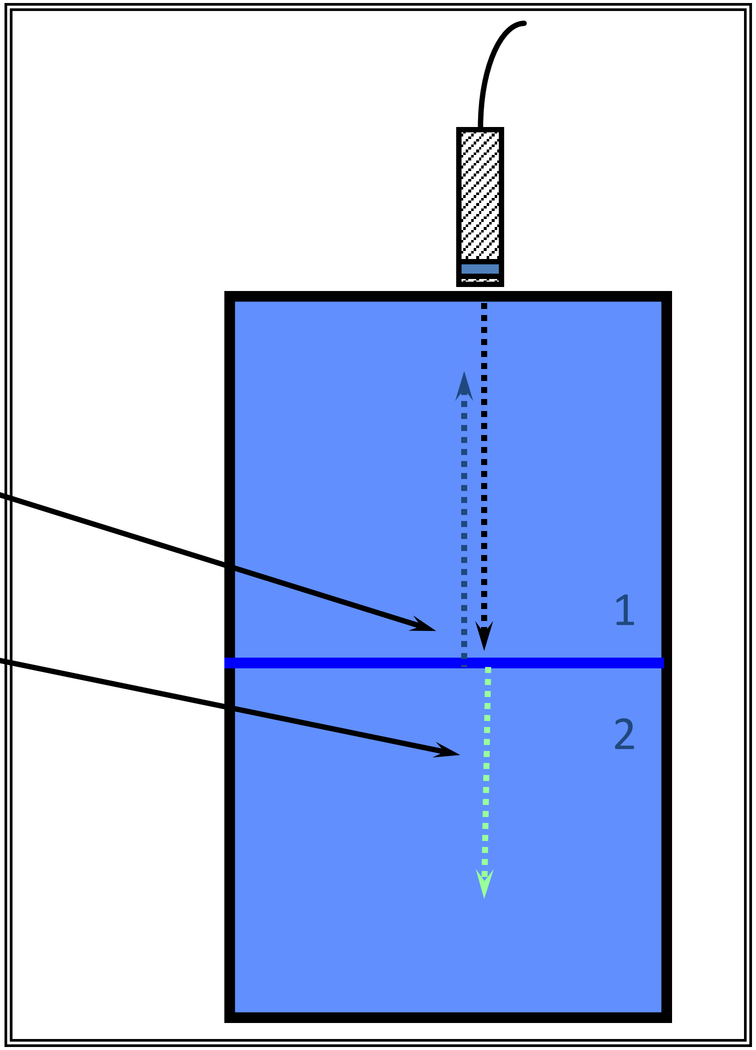
Perpendicular Incidence

- Sound beam travels <u>perpendicular to boundary</u> between two media



Perpendicular Incidence

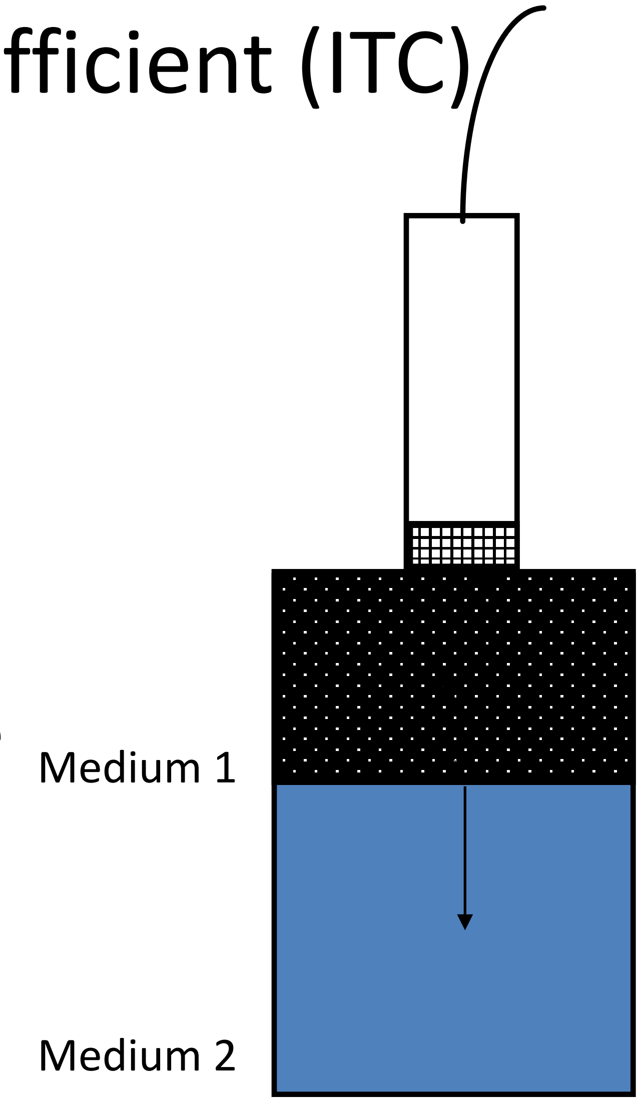
- at boundary part of the sound
  - **reflected**
    - sound returns toward source
  - **transmitted**
    - sound continues in same direction



Intensity Reflection Coefficient (IRC) & Intensity Transmission Coefficient (ITC)

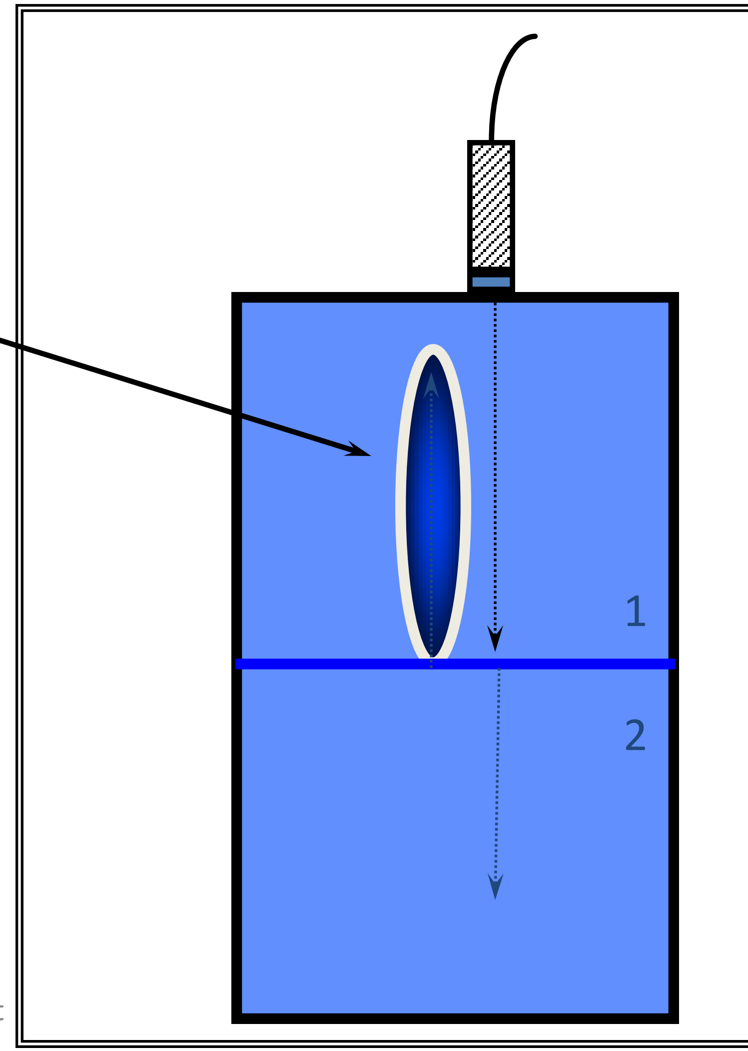
- IRC
  - Fraction of sound intensity reflected at interface
  - <1
- ITC
  - Fraction of sound intensity transmitted through interface
  - <1

$$\boxed{IRC + ITC = 1}$$



Perpendicular Incidence

- Fraction of intensity reflected depends on difference in acoustic impedances between the two media



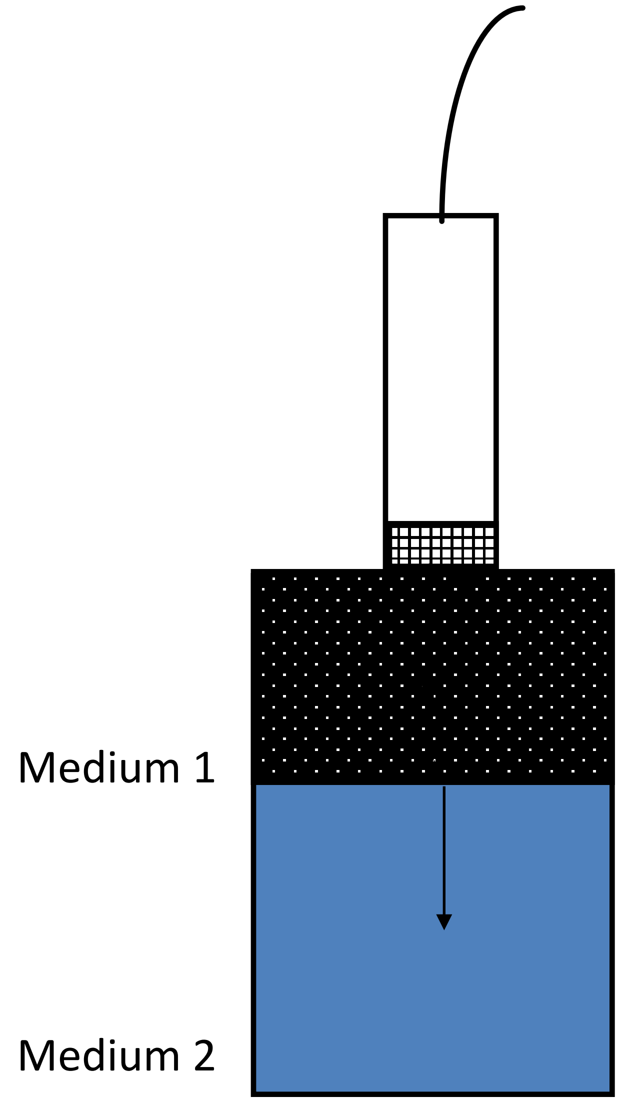
Acoustic Impedance =
Density X Speed of Sound

IRC Equation

For perpendicular incidence

$$\text{IRC} = \frac{\text{reflected intensity}}{\text{incident intensity}} = \left(\frac{z_2 - z_1}{z_2 + z_1} \right)^2$$

- Z_1 is acoustic impedance of medium #1
- Z_2 is acoustic impedance of medium #2



- Probabilities:
  - $Z_1 = Z_2$:
    - no reflections
    - materials are acoustically matched
  - Impedances are similar
    - little reflected
  - Impedances are so different
    - Example: soft tissue and air
    - virtually all reflected

$$IRC = \frac{\text{reflected intensity}}{\text{incident intensity}} = \left(\frac{z_2 - z_1}{z_2 + z_1} \right)^2$$

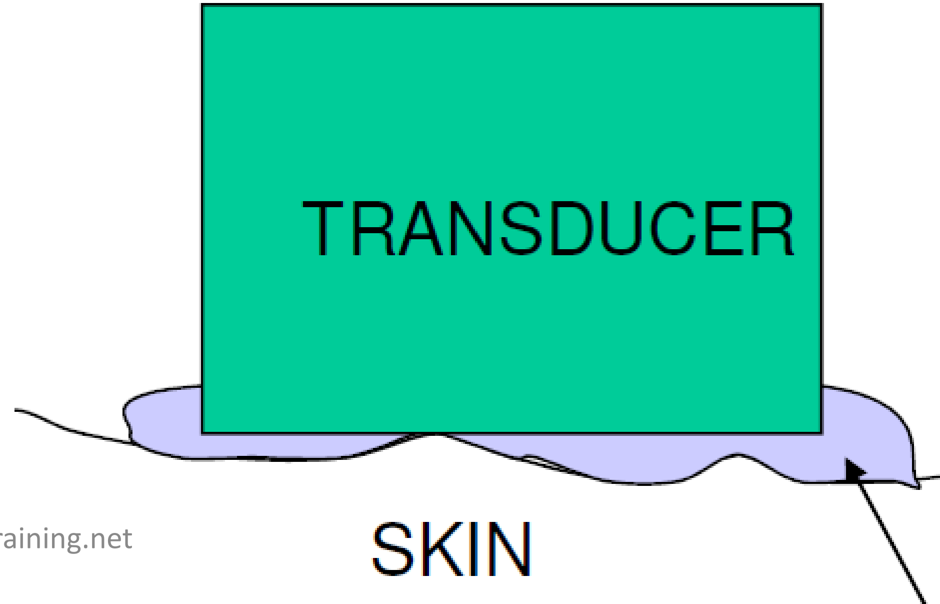
Applications

1- ultrasound gel:

$$IRC = \frac{\text{reflected intensity}}{\text{incident intensity}} = \left(\frac{z_2 - z_1}{z_2 + z_1}\right)^2$$

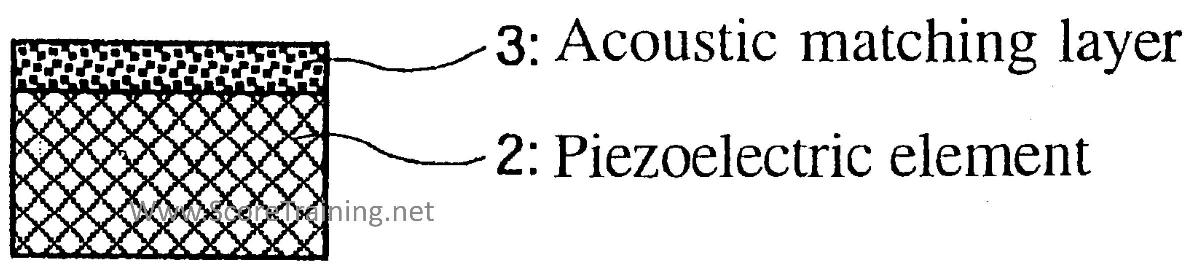
- Acoustic Impedance of air & soft tissue very different
- Acoustic Impedance of gel & soft tissue very similar
- Without gel virtually no sound penetrates skin

	Acoustic Impedance (rayls)
Air	400
Soft Tissue	1,630,000



2- matching plate:

- Z of transducer and tissues are mismatches → only 20% of sound waves are transmitted in either directions
- Solution: insertion of matching plate
  – Characteristic: made of plastic (Z is intermediate between transducer and tissues)
  – Place: at the front face of the transducer
  – plate thickness: ¼λ



Notes:

- There is subtle differences in Z between different soft tissues → small fraction is reflected at interfaces between soft tissues (e.g. 1% at fat kidney interface)
- Reflections less than 0.01% are unlikely to be detected
- At interface between bone and tissues 30% is reflected , yet , it is not possible to image through the bone

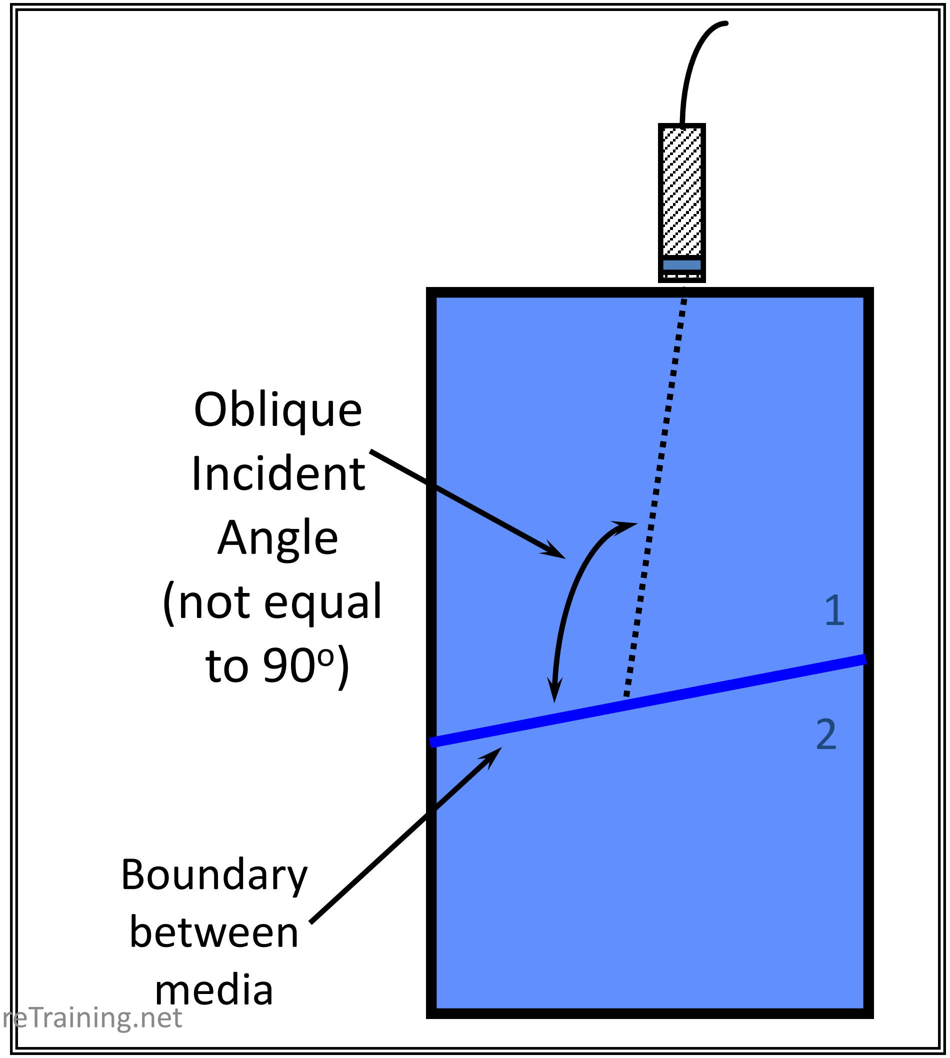
Oblique Incidence

- Sound beam travel not perpendicular to boundary
- Three probabilities:

1- specular reflection

2-diffuse reflection

3- scattering



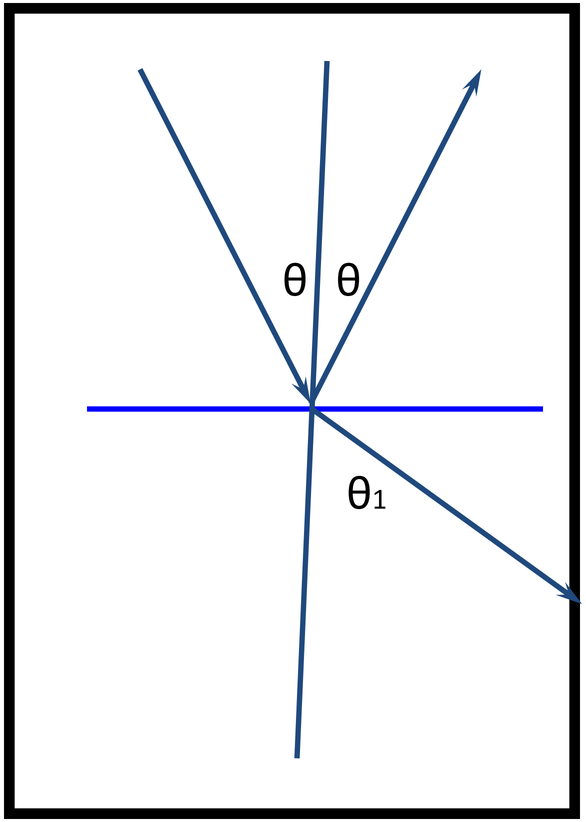
Specular Reflections

- Occur when the beam strikes a large smooth interface at an angle
- The sound undergoes reflection and rarefaction

  1) reflection similar to light reflection from mirror
     - Angle of reflection = angle of incidence

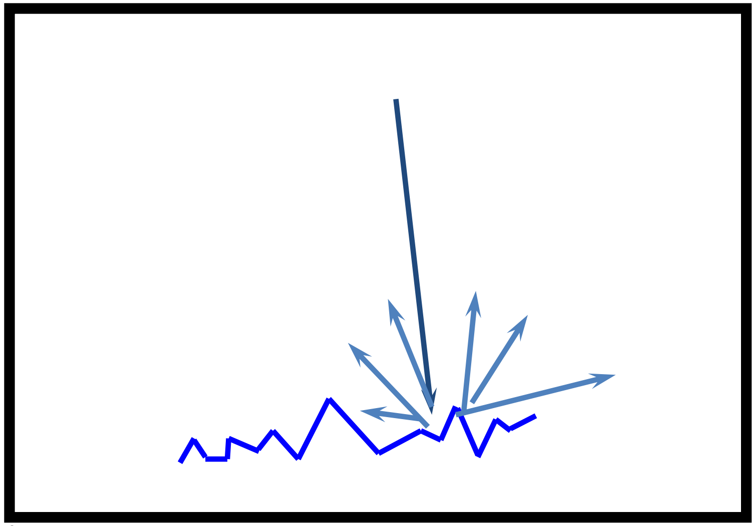
  2) rarefaction:
  - snell's law: ratio of sines of the incident and rarefaction angles is equal to ratio of sound velocity in the two materials

  i.e. $\sin\theta / \sin\theta_1 = C/C_1$



Diffuse reflection

- Tissue interface is rough and has undulations ≈λ
- The reflected beam spread out over an angle
- Same effect seen with light and frosted glass
- The spread become wider with:
  - Shorter λ
  - Rougher surface
- Result: transducer will receive some reflections even if the beam does not strike the interface exactly at a right angle



Scattering

- Condition: structure size is just < λ
- Result: sound is scattered equally in all directions
- This allows even small structures to be visualized (some scatter will reach the transducer)
- Examples:
  - echo signals produced inside tissue parenchyma (e.g. liver), which is about 1-10% as strong as those produced at organ boundaries
  - RBCs (basis of Doppler)
    - Why does Doppler require high frequency?
      - higher frequency results in more backscatter

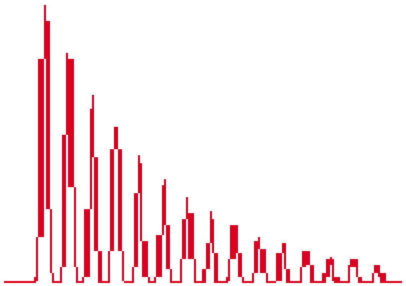
N.B:

- specular reflection very <u>angle dependent</u>
- backscatter not angle dependent

Sound Attenuation

Attenuation

- Definition:
  - Reduction in amplitude & intensity as sound travels through medium
  - Sound is Attenuated exponentially with the depth the sound travels
- Causes
  - absorption
    - sound energy converted to heat by frictional forces
  - reflection
  - Scattering

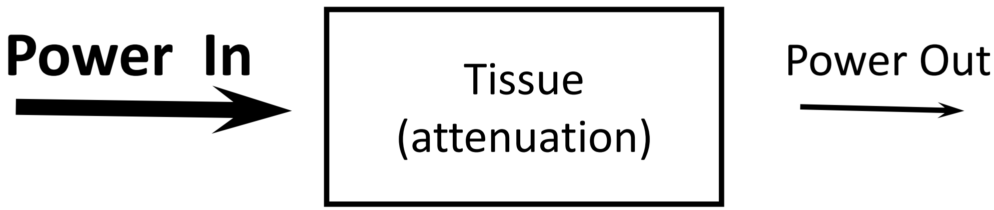


Unit of attenuation

decibels (dB)

No. of decibels = 10 x log power ratio

Power Ratio = Power Out / Power In



Notes:

- +ve dB means sound amplification
- -ve dB means sound attenuation (dB indicates <u>fraction of intensity lost)</u>
- Decibel values are additive

Power Ratio = Power Out / Power In

$$dB = 10 \times \log_{10} [\text{power ratio}]$$

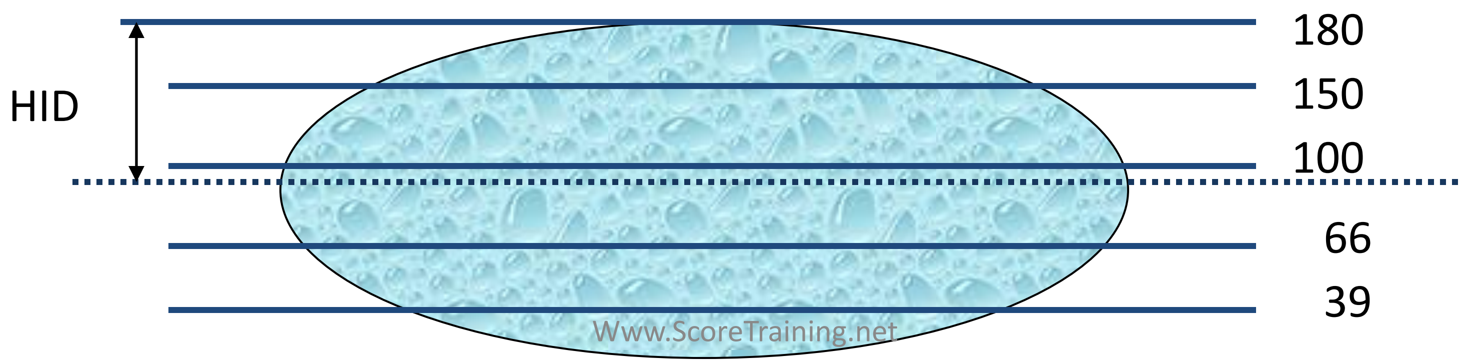
Decibel calculation

Power ratio	dB
1	0
10	10
100	20
1/100	-20
2	3

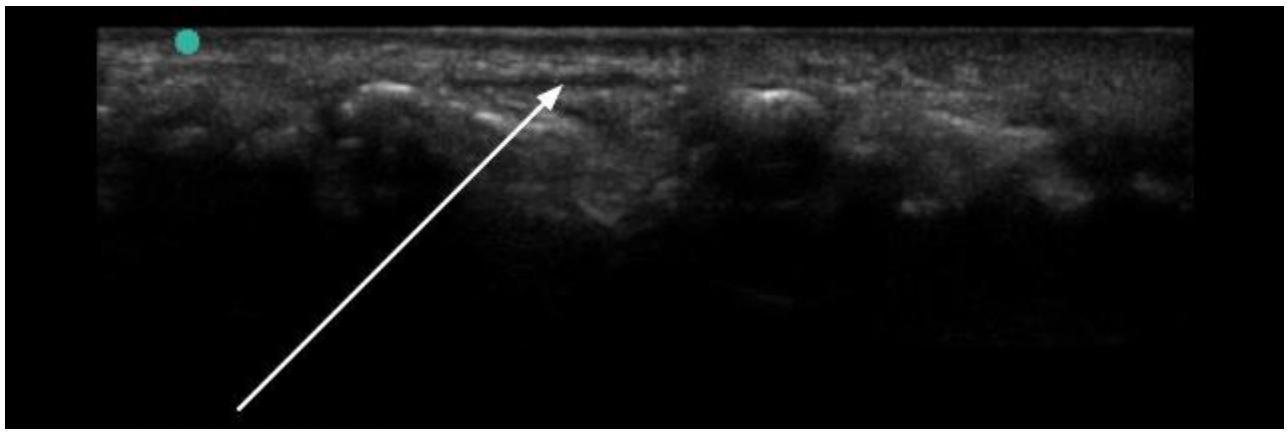
$$dB = 10 \times \log_{10} [\text{power ratio}]$$

Notes:

- Every decrease of 10 dB indicates another factor of 10 times attenuation
- Thickness of tissues that reduce sound intensity to half of its original value (result in -3dB) = half value layer = half intensity depth
- Ultrasound attenuation limits maximum imaging depth



- Attenuation affected by
  - Medium (see next)
  - frequency
    - As frequency increases, attenuation increase
    - high frequency = poorer penetration



N.B: Beam penetration (cm) = 40/Frequency

= depth at which the beam intensity has fallen too low to be useful

Attenuation In Soft Tissue

– Sound lose 1 dB / cm depth / MHz

- →For 1MHz U/S : half value layer of soft tissues = ...
- →for 3.5 MHz U/S: sound loss is …….. dB/cm
- →for 3.5 MHz U/S: total sound loss during imaging an object at 15 cm depth = ……….. dB

N.B:

Attenuation Coefficient: indicates fraction of beam intensity lost per unit distance of sound travel

Attenuation Coefficient = 1 * Freq.
(dB/cm) (dB/cm/MHz) * (MHz)

→Attenuation = Attenuation Coefficient X Path Length

Attenuation In water

– There are little attenuation of ultrasound in water

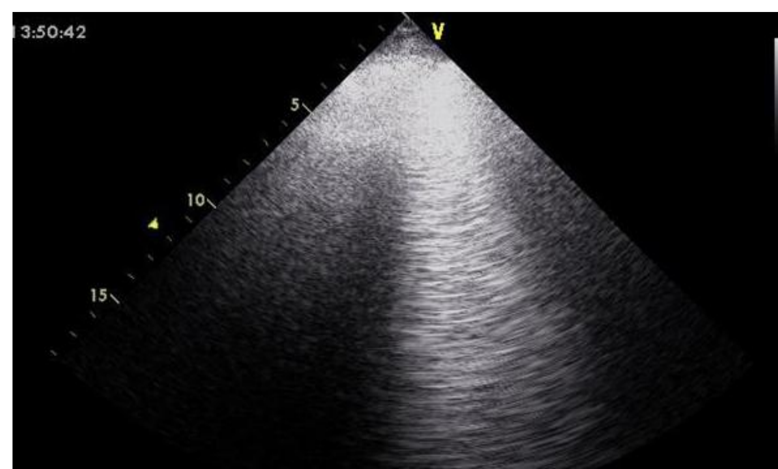
– Q. why pelvic U/S is done with full UB?

Attenuation In bone

– 35 dB /cm at 2.5 MHz

Attenuation In air

– 40 dB /cm at 1 MHz




THANK
YOU
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